DEFENSE AR JOURNAL

A Publication of the Defense Acquisition University

ISSUE 52 October 2009 Vol. 16 No. 3

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The *Defense Acquisition Review Journal*, formerly the *Acquisition Review Quarterly* journal, is published quarterly by the Defense Acquisition University (DAU) Press. Postage is paid at the U.S. Postal facility, Fort Belvoir, VA, and at additional U.S. Postal facilities. Postmaster, send address changes to: Editor, *Defense Acquisition Review Journal*, DAU Press, 9820 Belvoir Road, Suite 3, Fort Belvoir, VA 22060-5565. For free copies, mail written requests with an original signature to the above address using the subscription form provided in this journal. Some photos appearing in this publication may be digitally enhanced. ISSN 1553-6408.

Articles represent the views of the authors and do not necessarily reflect the opinion of the DAU or the Department of Defense.

The ***Defense Acquisition Review Journal***
is available electronically on the DAU Home Page at
http://www.dau.mil/pubscats/Pages/Defense%20ARJ.aspx

DEFENSE ARJOURNAL

A Publication of the Defense Acquisition University

The ***Defense Acquisition Review Journal (ARJ)*** is a scholarly peer-reviewed journal published by the Defense Acquisition University (DAU). All submissions receive a blind review to ensure impartial evaluation.

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Incremental development entails the deliberate deferral of work to a subsequent period, using technology maturity as the measure of readiness. This article illustrates that this approach might enable more effective delivery of the first increment with a comparison of two major systems as case studies. But there are some inherent risks in an evolutionary approach as well, and the authors caution that certain attributes of hardware products might help determine the suitability of evolutionary development methodologies. Mutable products with costless production, continuous requirements, low maintenance, or time criticality may be more likely to reap advantages from evolutionary approaches. Products that are nearly immutable, have binary requirements for key capabilities, require man-rating, or are maintenance-intensive may not be best candidates for incremental development.

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What Performance Based Logistics Is and What It Is Not—And What It Can and Cannot Do
Bill Kobren

Although Performance Based Logistics (PBL) sustainment strategies have been used successfully for the last decade, misperceptions persist. This article discusses what PBL is and is not; and what it can and cannot do for the military services, program managers, and ultimately the warfighter. PBL is not about contractors on the battlefield or outsourcing organic workload. It is about weapon system performance, readiness, best value outcomes, capability, and effective and efficient warfighter support. PBL represents a fundamental change in how DoD supports its weapon systems and ensures those systems are reliable, maintainable, and available when and where the warfighter needs them. When it comes to delivering performance outcomes: PBL works.

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Joint Acquisition Command Doctrine—A Success Story

Al Borzoo, Constance S. Short, Ken Brockway, and Col Stan L. VanderWerf, USAF

In the past, war planners typically treated acquisition as an afterthought. Operations Iraqi Freedom and Enduring Freedom Joint Task Force commanders were not initially afforded the full value of acquisition capabilities to buy local resources and manage the exploding number of contractors in the Area of Responsibility (AOR). Recognizing this shortfall, DoD created the Joint Contracting Command (JCC). The JCC provided substantial contracting capacity and coordination—critical attributes to effective, efficient AOR operations. This research and resultant report, originally prepared in 2006 for the Industrial College of the Armed Forces, played a substantial role in shaping joint thinking, culminating in creating Joint Publication (JP) 4-10, *Operational Contract Support*. JP 4-10 establishes long-needed joint contracting doctrine for Combatant Command AOR operations.

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Application of Systems Engineering to Rapid Prototyping for Close Air Support

John M. Colombi and Richard G. Cobb

Twenty-first century military operations have brought forth many new challenges for the Armed Forces of the United States. One such challenge is with new operating environments, where current systems are not always effective. While it is desirable to apply a systems engineering approach to best meet critical user needs, there may be a misconception that systems engineering requires a lengthy and detailed process not nimble enough for a rapid prototyping effort. This article describes how a classic systems engineering methodology was successfully tailored to the rapid development of potential material solutions to meet a critical operational need. Key observations are drawn from this experience and formulated into heuristics for tailoring systems engineering for future rapid prototyping efforts.

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Can Applying Organic and Industry Best Practices Improve Foreign Military Sales Supportability?

Brian B. Yoo, Duane W. Mallicoat, and Timothy "Tim" K. Simpson

This article provides a brief overview of Foreign Military Sales (FMS), its role in the ever changing dynamic environment that we live in, and finally how some of the specific FMS processes can be improved through the application of logistics best practices and initiatives. The ultimate goal is to continually improve the processes associated with FMS to create a win-win scenario for the Department of Defense and affected stakeholders. The best practices within the framework of the ten integrated logistics support (ILS) elements discussed within this article should be merged into the current acquisition or logistics support strategy.

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A Multi-Criteria Decision Model for Migrating Legacy System Architectures into Open System and System-Of-Systems Architectures

Cyrus Azani

Full-spectrum dominance in battlefield, cost-effective development of capabilities, timely reaction to evolving threats and technologies, and system and process flexibility can be greatly enabled through the application of open systems strategies. Such strategies are effective business and technical approaches for assessing the appropriateness of developing modular and open architectures for stand-alone as well as system of systems. This article will introduce an integrated methodology for assessing existing systems and migrating their architectures into modular and open architectures. The proposed method integrates open systems strategies with the Analytic Hierarchy Process (AHP) and Goal Programming (GP)—two powerful decision-making models—to evaluate the appropriateness of open systems migration, rank migration candidates, allocate resources among them, and develop open architectures for selected systems.

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Games for Good—
How DAU Is Using Games to Enhance Learning
Alicia Sanchez

The use of *games* has become a popular initiative in many learning organizations. The Defense Acquisition University, by targeting enhanced outcomes for learners and using innovative, multiple approaches to develop games and simulations that are engineered to yield performance-oriented outcomes, has created a unique opportunity to reach an evolving workforce on multiple levels. Through the use of story and interaction, students gain a better understanding of the dynamic application of course content, while fostering motivation to learn and increasing perceived relevance of the instruction. This article covers the use of games and simulations in three different initiatives: Games in Curriculum, Games in Continuous Learning Modules, and Mini-Games—each of which was created with the end result of learning in mind.

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LETTER

FROM THE EDITOR

I am excited to announce the lineup of research articles for Issue 52 of the *Defense Acquisition Review Journal*. The first article, "From Amorphous to Defined: Balancing Risks in Evolutionary Acquisition," by COL John T. Dillard, USA (Ret.) and David N. Ford, provides a thought-provoking analysis of Evolutionary Acquisition (EA). Their goal was to offer meaningful and practical recommendations to program managers concerning the effective results and successful implementation of EA. Spiral development is a management strategy designed to reduce risk, but the nature of how this strategy is applied can introduce additional and different risks. The authors suggest that a single methodology for DoD system development may not be appropriate, and they provide analysis of when and how spiral development can be used most effectively. Stability is a critical characteristic in any program—stability in requirements, design, technology, configuration, and most of all, funding. In an unstable world with an uncertain future, the only constant is change. This article will help program managers cope with change.

In the second article, "What Performance Based Logistics Is and What It Is Not—And What It Can and Cannot Do," author Bill Kobren gives our readers a complete description of Performance Based Logistics (PBL) with an impressive assessment of what PBL is and what it is not. The author strongly asserts that as a strategic readiness imperative, PBL works! Kobren makes the case that PBL delivers substantial improvements in performance with lower costs across the life cycle, providing more for the warfighter with less from the taxpayer. PBL is about weapon system performance, readiness, best value outcomes, capability, and superior support to the warfighter. PBL represents a fundamental change in how DoD supports its weapon systems and ensures those systems are reliable, maintainable, and available in the most cost-effective manner.

The next article, "Joint Acquisition Command Doctrine—A Success Story" by Al Borzoo, Constance S. Short, Ken Brockway, and Col Stan L. VanderWerf, USAF, provides great insight and background into the development of Joint Publication 4-10, *Operational Contract Support*. Prior to the publication of JP 4-10 in October 2008, acquisition had been mostly an afterthought in war planning. As a result, field commanders in Operations Iraqi Freedom and Enduring Freedom were not afforded the full value of acquisition capabilities to buy local resources and manage the rapidly growing number of contractors in the operations area. In today's dynamic military environment, contractors have become critical to Joint Task Force Operations. As operations in Iraq were to prove, insufficient contractor support planning placed great strains on the military's ability to manage its contractors. While contracting efforts were ultimately successful, insufficient contract-management capacity and coordination led to substantial efficiency losses and a reduction in effectiveness. JP 4-10 now addresses these issues and establishes long-needed joint contracting doctrine. Research for this article provided many recommendations, which were used in the development of JP 4-10.

In the fourth article, "Application of Systems Engineering to Rapid Prototyping for Close Air Support," John M. Colombi and Richard G. Cobb present and analyze a case study for successful rapid prototyping without compromising sound systems engineering principles. Twenty-first century military operations have brought forth many new challenges for the U.S. Armed Forces. One such challenge is with new unexpected operating environments,

where current systems are not effective. While it is desirable to apply a systems engineering approach to best meet critical user needs, there may be a misconception that systems engineering requires a lengthy and detailed process not nimble enough for a rapid prototyping effort. This research article describes development of the Friendly Marking Device (FMD) that allows a ground controller to quickly and accurately identify the position of friendly ground personnel to close air support aircraft. The authors conclude that the FMD project successfully applied systems engineering principles to take critical user needs and rapidly produce viable prototypes that could be quickly transitioned to production. Key observations and lessons learned are discussed.

The following article, "Can Applying Organic and Industry Best Practices Improve Foreign Military Sales Supportability?" by Brian B. Yoo, Duane W. Mallicoat, and Timothy "Tim" K. Simpson delivers a comprehensive look at the history of the Foreign Military Sales (FMS) program and an analysis of FMS processes. Several specific examples of FMS cases are presented, and several Integrated Logistics Support (ILS) elements are covered in detail. The FMS program is authorized by the Arms Export Control Act and conducted using formal contracts or agreements between the U.S. Government to sell weapon systems to authorized foreign purchasers. The activity of selling weapon systems to foreign governments becomes a leveraging tool of U.S. foreign policy and provides the United States an avenue to conduct joint operations with the receiving nation. The authors make the case that FMS is a critical tool in promoting U.S. foreign policy and national security interests.

The sixth article, "A Multi-Criteria Decision Model for Migrating Legacy System Architectures into Open System and System-of-Systems Architectures" by Cyrus Azani, explores the application of the Modular Open Systems Approach (MOSA). Rapid reaction to evolving threats and technology requires agile system architectures that could quickly and cost effectively be integrated and reconfigured within family of systems and joint system of systems warfighting constructs. Affordable agility and reconfiguration demands open and modular forces, systems, and system of systems. Full-spectrum dominance on the battlefield, cost-effective development of capabilities, timely reaction to evolving threats and technologies, and system and process flexibility can be greatly enabled through the use of MOSA. This approach is an effective business and technical strategy for assessing the appropriateness of developing modular and open architectures for single systems as well as for family and system of systems. This article introduces an integrated methodology for assessing the migration of existing system architectures into modular and open architectures.

The final article, "Games for Good—How DAU is Using Games to Enhance Learning" by Alicia Sanchez, is the second in our new series of technology articles from DAU. Sanchez summarizes some of the efforts being made at DAU to more fully integrate Games and Simulations into its courses. The use of Games and Simulations can be an extremely valuable learning tool enabling increased comprehension and retention. Sanchez is leading the way for increased application of Games and Simulations in DAU courses and other learning products.

Dr. Paul Alfieri
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DEFENSE ACQUISITION REVIEW JOURNAL

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FROM AMORPHOUS TO DEFINED: BALANCING RISKS IN EVOLUTIONARY ACQUISITION

COL John T. Dillard, USA (Ret.) and David N. Ford

Incremental development entails the deliberate deferral of work to a subsequent period, using technology maturity as the measure of readiness. This article illustrates that this approach might enable more effective delivery of the first increment with a comparison of two major systems as case studies. But there are some inherent *risks* in an evolutionary approach as well, and the authors caution that certain attributes of hardware products might help determine the suitability of evolutionary development methodologies. Mutable products with costless production, continuous requirements, low maintenance, or time criticality may be more likely to reap advantages from evolutionary approaches. Products that are nearly immutable, have binary requirements for key capabilities, require man-rating, or are maintenance-intensive may not be best candidates for incremental development.

Keywords: *Evolutionary Acquisition, Spiral Development, Incremental Product Development, Risk, Javelin, ATACMS*

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Risk vs. Evolutionary Acquisition

Since his work in the 1830s, Charles Darwin has received much of the credit for furthering a theory of biological evolution. While not the first to have the idea, he associated observations of species variety on the island of Galapagos with species environment, and suggested that nature selected the variations that were the fittest (Darwin, 1859). In its time (and since), the idea was considered radical and a threat to religious and social order. Mere variety itself can be controversial since, paradoxically, variety is appreciated in some domains (Ashby, 1960) and abhorred in others (Neave, 2000).

At the center of *evolutionary acquisition* are also ideas and phenomena about variety and change. As a policy for system development, it too is controversial. And as within Darwinian concepts, product evolution involves information transfer, interaction with the environment, and unpredictability of change outcomes. But unlike evolutionary biology, product variations and selections occur frequently and are non-random. Much of what we have found in the following research on evolutionary development and project management is about how managers must cope with product variety and change. Using case study analyses, review of current subject literature, and computational modeling (expounded upon in a companion article: Ford & Dillard, 2009), the focus of our research was to ascertain the program management implications of evolutionary acquisition, obtain lessons learned in past programs as applicable to future development efforts, model and simulate projects that used different acquisition approaches, derive predictions, and make recommendations to project managers for the effective and efficient harnessing and implementation of evolutionary acquisition.

Background

The Department of Defense (DoD) promulgated evolutionary acquisition (EA) as policy in 2000, and soon after, *spiral development* for the preferred acquisition strategy of all materiel (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2000). EA's goal is to time-phase system requirements and provide capabilities sooner. But confusion over terms persists, despite further elaboration and even codification in statute (Armed Forces, 2002), along with a lack of full understanding of many policy implications—especially some inherent risks. DoD policy for evolutionary acquisition mandated spiral (i.e., amorphous and unplanned requirements/technologies) or incremental (i.e., defined and deferred requirements/technologies) development methodologies for all programs. Since all amorphous spirals eventually become defined increments, the disappearance of this term "spiral" in most recent (2008) policy will not be missed.

Fundamentally, EA means there will always be multiple product releases of an item. The current policy thrust is primarily about the reduction of product cycle time within an uncertain environment by using mature technology exclusively. The DoD's requirements process has also followed with "evolutionary" requirements

documents—a new idea. Uncertainty is the usual realm of program managers (PM), especially in defense systems, and is usually dealt with by seeking best information (Pich, Loch, & De Meyer, 2002). Earlier reform initiatives were aimed at overcoming information gaps and technology lag. For example, the 1990s Integrated Product and Process Development initiative was about collaboration for early and complete requirements realization. However, the current paradigm is to allow uncertainty in requirements to resolve over time and endeavor only what is immediately achievable. The Government Accountability Office (GAO) has also urged the DoD to move toward Knowledge-Based Acquisition, with Technology Readiness Levels (TRL) as the rubric for program initiation (advanced development) (GAO, 1999a). Thus, at the very heart of EA is the exclusive use of mature technology to reduce project scope.

Observations and Assessments: Implications of the Policy

We have managed and observed development efforts that employed evolutionary development approaches successfully. Two development programs of the 1990s—the Army Tactical Missile System (*ATACMS*) and the *Javelin* anti-tank missile system—were compared herein with regard to their differing acquisition strategies, TRLs, and program outcomes. Our study results support that a more effective delivery of the first increment might be facilitated with an evolutionary approach. However, the latest EA policy implications and outcomes are yet to be fully known, and some authors have already expressed insightful strategic and institutional oversight concerns (Sylvester & Ferrara, 2003). We have also described operational program management concerns about its implementation, including excessive decision bureaucracy, organizational challenges from multiple and concurrent development efforts, outmoded technology at release, funds forecasting, transaction costs, and maintenance of subsequent increment priority (Dillard, 2005). Our additional findings suggest that incremental development may not be appropriate as a one-size-fits-all strategy.

VARIETY AND COMPLEXITY

For example, variety and complexity are elements of project risk. While variety and product diversity are preferred by market consumers to satisfy mainstream and smaller niche needs, variety adds complexity in production and is costly for hardware manufacturers and owners alike. In support of EA policy, the GAO has often used product examples such as home appliances and commercial vehicles, which tend to ignore product variety from the vantage point of fleet owner vs. that of the producer (GAO, 1998a, 1998b, 1999b, 2003). The DoD is unique in that it almost entirely outsources capital projects for exclusively internal use, and this aspect of lifelong ownership of an entire

fleet of systems presents a different relationship than, for example, a product manufacturer may have with its production aircraft.

Traditional views about variety from late design changes are usually negative, except for producibility savings and performance enhancements. Changing production configurations is not viewed as efficient due to supportability issues (regarding spares and maintenance) with lot, model, and type diversity. RAND's study of support considerations for the current mixed configuration fleet of Unmanned Aerial Vehicles (UAV) reported, "Multiple aircraft configurations drive *multiple spare component packages* and, in the most extreme cases, may drive *multiple pieces of test equipment*, all significantly increasing long-term support costs" (Drew, Shaver, Lynch, Amouzegar, & Snyder, 2005; emphasis added). Reliability issues can also emerge because of insufficient testing of the changes. Depending on the degree of change, system validation and qualification become a concern if changes are not under strict control. There may be backward compatibility and interoperability issues as well. Another burden is the training impact of mixed capabilities within the force or even within the same owning and operating unit.

Higher levels of risk from system complexity are generally believed to be mitigated by control measures, as within organizational contingency theory (i.e., centralization/decentralization, etc.). The American nuclear Navy was rooted in CAPT Hyman G. Rickover's visit to Oak Ridge National Laboratory in 1946 to investigate the feasibility of using nuclear power aboard submarines. During his long tenure as head of the nuclear program, he maintained fundamental principles about technical and organizational program structures, not the least of which was personal accountability. Those who have worked with acquisition of nuclear plant materials know well both the specifications and standards of quality that are unique to this commodity, as well as Rickover's tenets of responsibility and accountability that are still in place. They are largely believed to be important aspects of how he successfully dealt with the complexities and uncertainties of a new application of technology. The *Guide to the Project Management Body of Knowledge (PMBOK)* (Project Management Institute, 2004) also asserts that change in the course of projects and products is inevitable and mandates the need for a disciplined change-control process to control its impacts—from inception to completion. Many other useful theorems on systems complexity, change, and control exist to alleviate unwanted variation in development and production.

CYCLE-TIME AND PHASE CONCURRENCY

We have observed that, though concurrency is a necessary ingredient for efficient project management, it has also long been correlated with risk (due to interdependence of activities) and might vary significantly with the types of activities underway—inferring that periods of stable production configuration between development increments reduce complexity in program structure and attendant risks. Cycle-time for the development of each increment, and the

relatively successive or concurrent phasing of the follow-on increments, will also have a definite impact on program structure, budgeting, project complexity, and organizational issues, etc. For reasons that we have brought forth in our work on the computational modeling of evolutionary development, we have concerns about the conduct of incremental development programs with continual and highly concurrent phasing of development increments.

THE MORE PROJECTS THAT SPECIALISTS SUPPORT, THE LESS THEY ARE PROPORTIONATELY AVAILABLE TO THE PROJECTS DUE TO "QUEUING INEFFICIENCIES."

Particularly in matrix organization structures, as is often the case with projects, there can be a tendency to staff multiple projects with a single specialist. The more projects that specialists support, the less they are proportionately available to the projects due to "queuing inefficiencies." Their availability decreases because of the need for transition between projects (physical, mental, learning curve, etc.). This has at times resulted in large delays in project completion (Smith & Reinhartsen, 1998). Similarly, Ibrahim (2005) has shown that discontinuous enterprise membership is a contributing factor toward knowledge loss in organizations involved in large complex product development processes. Examining knowledge flows across product life cycles reveals that members often are not engaged in all phases. Whether from rotation of duties or multi-tasking, a discontinuous member's inaccurate knowledge could cause a functional error at the individual level, which is not immediately obvious at the enterprise's overall project level. Ibrahim's findings support observations of knowledge loss continuing despite investments in information technology and knowledge management.

Development Case Studies

One of the most recent monographs we found on emerging results of evolutionary acquisition is by RAND—on five immature, non-man-rated space systems. Space systems are somewhat different than general force defense projects (in their quantities produced, their operational space environment, greater proportional front-end investment, and technology development periods). RAND also found that evolutionary policy confusion persists and that EA added program complexity and uncertainty, especially with regard to budgeting. Extending their findings to non-space DoD programs, RAND highlighted the EA challenges of programmatic flux (Drew, Shaver, Lynch, Mahyar, & Snyder, 2005). They feel, and we agree, that EA presents the opportunity for typical non-space project management challenges to be even more formidable.

For such traditional defense systems, as expository cases of evolutionary acquisition, we analyzed two tactical missile programs that illustrate both planned and unplanned change: the Army Tactical Missile System (ATACMS) and the Javelin Anti-Tank Weapon System (Dillard & Ford, 2007). Both of these systems began as Defense Advanced Research Projects Agency (DARPA) programs in the 1980s and were fielded to forces and employed in combat in the 1990/2000s. See the full report at http://www.acquisitionresearch.net/_files/FY2007/NPS-AM-07-002.pdf for a detailed description of these case studies and our use of them to investigate evolutionary acquisition with computational modeling.

ATACMS employed both incremental and spiral strategies for product development, benefiting from an elegant, modular independent architecture. This program was able to omit its technology development phase by employing mature technologies for a leap-ahead capability in range. The basic system arrived essentially on budget and schedule, with several successive variants, both pre-planned and unplanned. Years later, one instance of a minor production change (uncontrolled variety) caused missile failure and a costly refit of already-produced missiles.

In contrast, Javelin used the single-step-to-full-capability approach for product development. With much greater modular interdependence, the program embarked upon advanced development with immature technologies in several critical areas—causing significant cost and schedule overruns. The system has also experienced subsequent design changes and product variety, but they have consisted more as running production changes than as product variants or blocks.

A comparison of the development and use of technology in the ATACMS and Javelin projects clearly illustrates the impacts of technology maturity on first increment project performance. The Table compares the technology maturity in the ATACMS and Javelin projects by identifying the Critical Technologies for seven subsystem categories that both products employed. For each subsystem, the Technology Readiness Level of the critical technology used at the time of insertion into the development is shown. The ATACMS project used only critical technologies with a minimum TRL of 6 and an average of 8.1. In sharp contrast, the Javelin project used technologies with a maximum maturity of TRL6 and an average of TRL5. The ATACMS project used significantly more mature technology than the Javelin project and reaped the rewards of program success.

The relative cost and schedule performance of the ATACMS and Javelin projects reflects the differences in the use of technology. The ATACMS project had no Advanced Development Phase Contract Cost Growth and only 6 percent schedule growth in the Advanced Development Phase. But the Javelin project experienced over 150 percent cost growth and 50 percent schedule growth in Advanced Development. The poorer project performance when less-than-mature technology was used supports the potential effectiveness of EA in managing technology risk.

TABLE. COMPARISON OF PROGRAMS USING DIFFERENT DEVELOPMENT APPROACHES AND TECHNOLOGY READINESS LEVELS

Key Program Characteristics - First Increment of Capability

Program Aspects	ATACMS (Evolutionary)		Javelin (Single-Step)	
DARPA Predecessor	Assault Breaker 1977-82		Tank Breaker 1981-82	
Ultimate Capability	*"Deep Attack"*		*"Fire and Forget"*	
Subsystem	Critical Technology	TRL	Critical Technology	TRL
Munition	Lance M74 Bomblet	9	Tandem Shaped Charges	5
Propulsion	Solid Rocket Motor	9	Two-Staged Solid Rocket Motor	5
Flight Control	Fin Surfaces	9	Fin + Thrust Vector Control Vanes	6
Guidance and Control	Inertial	9	Tracker Software Algorithm	4
Safe/Arm Fusing	Mechanical	7	Electronic	4
Software Function (Target Acquisition, Fire Control, etc.)	Various	6	Various	6
Sensor	N/A	-	Focal Plane Array	5
Cost of Development	~$700M		~$700M	
Contract Type	Fixed Price		Cost Reimbursable	

Tech Development Phase	0 Months	27 Months
Advanced Development Phase—Planned	48 Months	36 Months
Advanced Development Phase—Actual	51 Months	54 Months
Total Time in Development	51 Months	81 Months
Advanced Development Phase Schedule Growth	6%	50%
Advanced Development Phase Contract Cost Growth	0%	150%

Synthesis of these cases reveals that as an approach oriented primarily on the reduction of product cycle-time, evolutionary development is highly facilitated by the leveraging of mature technologies. Also, system mutability, along with other factors discussed in the next section—such as time criticality (user risk) and modular interdependency—can bolster incremental development suitability. For ATACMS, an "open," or at least elegant, architecture was fundamental for modular variety, and thorough design specification and configuration management accountability proved essential for managing the complexity of multiple product releases. In the case of the Javelin, key capabilities depended upon immature technologies and at least one binary requirement, to the detriment of project cost and schedule outcomes. In stark contrast, modular interdependence was manifested by an almost total system redesign for lengthy and costly weight reductions.

Do Product Attributes Affect Evolutionary Applicability and Outcomes?

More questions about EA include whether products with different attributes (e.g., hardware vs. software, buildings vs. electronics) may lend themselves more or less to the use of an incremental development approach. From the literature and cases we examined, we offer the following other product attributes for PMs' careful consideration when planning product capability increments.

MUTABILITY

Perhaps our foremost reservation is the appropriateness of the evolutionary development process for all project sizes and product commodities in toto, and the application of the spiral process to hardware products vs. Dr. Barry Boehm's (1985) original and most relevant application of this development approach toward software. Boehm himself warned of "hazardously distinct" spiral model imitations, and in his own words described his vision of the spiral process:

> The spiral development model is a risk-driven process model generator. It is used to guide multi-stakeholder concurrent engineering of software-intensive systems. It has two main distinguishing features. One is a cyclic approach for incrementally growing a system's degree of definition and implementation while decreasing its degree of risk. The other is a set of anchor point milestones for ensuring stakeholder commitment to feasible and mutually satisfactory system solutions (Boehm & Hansen, 2000, p. 3).

Clearly, the conceiver of this spiral notion was oriented upon amorphous requirements and continuous stakeholder inputs for the alleviation of project risk with a very mutable product (Boehm, 1988). The nature of software being

in the digital rather than physical realm, it is particularly conducive to rapid and successive revision and nearly costless production. And, Boehm encourages varying from the spiral model as needed and reverting to a sequential model if requirements are well established and the project less risky.

Multiple product increments do not often appear in large, static, singular projects such as bridges, highways, office buildings, or in other project areas that have typically long lead times or product cycles, such as feature-length films, pharmaceuticals, etc. These are what we call nearly immutable products and are much different than smaller projects (like rapid software application development) with much shorter development periods. However, as with almost everything engineered that we can observe in the physical world, even these things can evolve and change with additions, spin-offs, sequels (and prequels), expansions, etc. Mutability simplifies change, and that idea can be extended to many DoD projects.

USER RISK/SAFETY

For DoD, product attributes that are aligned with Boehm's notion of process models being driven by risk are those of mission or time criticality, survivability, and user safety. System safety is often described in terms of "man-rating" as approval for safe usage.

Time-critical or enhanced survivability systems. DoD's products have expanded risk considerations beyond Boehm's models of commercial software. Extending the idea of project risk-as-a-driver down to the level of the end user, it might seem logical to assume that time criticality of the need or mission (in which risk of not achieving project success actually endangers customer lives), might be a significant factor in the appropriate application of the evolutionary process for reduced initial product cycle-time. Perhaps defensive systems are a good example. The immediate need for a Rocket-Propelled Grenade defeater or an Improvised Explosive Device neutralizer for currently deployed forces in Iraq and Afghanistan, for example, clearly dictates that lives will be lost if a near-term capability is not achieved. We also cite as an example the National Missile Defense initiative in which, given the view of near-term threats, early deployment of even rudimentary capability has been deemed preferable to waiting for full capability. Such urgency likely precludes full and certain requirements specificity.

Non-man-rated and man-rated systems. In the same vein, non-man-rated systems (i.e., UAVs or cave-exploring robots—capabilities in which operator lives are not at risk if the product fails)—may also lend themselves readily to rapid innovation and riskless experimentation cycles. However, user hazard levels for man-rated systems may be an entirely different matter.

Man-rated systems present a different challenge. Configuration variety adds technical complexity with sometimes unpredictable interactions. In such projects as pharmaceuticals, aviation, vehicular transportation, etc., producers mitigate safety risks with thorough analyses, documentation reviews, validation testing, and other control and verification processes. By their very nature—with lethal hazards for the end user and typically lengthy approval criteria—these may not be good candidates for an evolutionary approach.

LOGISTICAL SUPPORT PLANNED DURING SERVICE/SHELF LIFE

Our observations warn that multiple configurations of hardware products come at a cost for fleet ownership. Veterans of new system deployments across the force/fleet, or throughout any large using organization, know the difficulties of rolling out a configuration change. Benefits of standardization have long been offered via production economies of scale, commonality of parts across platforms, and interoperability. If the ultimate goal is to have standardization across the DoD's force, owning multiple configurations (variety) of a system seems in opposition, with added complexity in training and supply support of the item. The logistical maintenance strategy cannot be ignored—whether the end-item is maintenance-intensive, such as tactical vehicles, or maintenance-free, such as with many electronics items and munitions, and situations in which physical changes are completely transparent to the user. For multiple-product configurations, the acquisition approach could have a huge effect on the total costs of ownership, as previously mentioned by Drew et al. (2005) in regard to UAVs.

RANGE OF REQUIREMENT ATTAINMENT

Most requirements are "continuous," i.e., may be satisfied in varying amounts of attainment. Thus, ranges of their satisfaction can be flexibly specified, allowing for thresholds (minimum values of attainment) and objectives (optimal values of attainment). Examples are range, accuracy, weight, reliability, etc. However, we have found that some requirements, often critical ones, are more binary in nature than continuous. They have a much narrower range of attainment, such that they are essentially pass/fail or go/no-go in their demonstration. Examples are Windows-compatibility, "soft" missile launch, network security, physical fit, leak-proof, shock-/vibration-/drop-proof, survivability, horizontal-to-vertical flight transition, etc. If one of these more binary-type requirements happens to be a Key Performance Parameter, its attainment will be on the project's critical path and highly dependent upon technical maturity. As such, it might practically dictate the length of the entire advanced development effort and make division into capability increments less beneficial as a development strategy. Though somewhat correlated with product reliability, these kinds of requirements demand a system that "either works or it doesn't" without the flexibility afforded by objectives and thresholds.

AMOUNT OF CHANGE—AND THE LURE OF MODULARITY

We subscribe to the current systems theorists' view that complexity is comprised of numbers (of components), connections (interdependencies) and distinctions (variety). Distinction corresponds to variety, to heterogeneity, and to the fact that different parts of complex systems behave differently (Heylighen, 1997). Variety is a component of Nobel Prize winner Herbert Simon's explanation of complexity—many different parts with many interactions. Simon argued, from his observation of complexity in things both natural and artificial, that complex systems evolve from simple systems. And, they do so more rapidly when there are stable, intermediate forms or sub-systems (like modules or "units of action") (Simon, 1981). Moreover, he argues the resulting evolution into the complex system will be hierarchical. Earlier, in *The Architecture of Complexity*, Simon (1962) proposed hierarchy as a universal principle of complex structures. He felt that complex problems could be solved more easily when decomposed into sub-problems (similar to how project managers employ Work Breakdown Structures via the Systems Engineering Process). And, sub-problem solutions could be combined into a solution for larger problems, etc.

Commonly seen today are modular industrial products that are sometimes designed as complete architectures, with standardized interfaces that invite others to introduce complementary products for insertion (Agre, 2003). The Modular Open Systems Approach (MOSA) is a relatively new DoD initiative that encourages the use of widely supported commercial interface standards and disciplined interface controls to develop systems architectures using modular design concepts (DoD Open Systems Joint Task Force, 2004).

As in biological evolution, improved "fitness" with a system's environment is sought in the adapting or evolving of systems. But others have noted that Simon's metaphors for dynamic complex systems, useful as they are for understanding complexity, fall short of explaining their evolution. While the concept of modularity suggests approximately independent subsystems may be modified or adapted as such, it has been shown that, in the aggregate, there is yet quantifiable modular interdependency that affects evolvability (Watson & Pollack, 2005). In other words, how changes in the state of one module affect the state of another is relative and measurable. Thus, Simon's writings illustrate that modularity is beneficial for production but not necessarily for evolution.

Examples of modular interdependency are plentiful. In the aircraft or automotive realm, an engine upgrade would intuitively seem to be a relatively independent subsystem change. But, systems engineers know that changes propagate through hardware almost as much as software in the long run—just as the eventual rise in building temperature from the thermostat adjustment in one modular room. For instance, adding increased armor protection (and weight) for deployed High Mobility Multi-purpose Wheeled Vehicles has resulted in increased wear-out of drive train and suspension components and impacts to vehicle range, mobility, mileage, etc. As a result, "up armor" kits have become only a stopgap measure until totally redesigned systems can be produced.

Thus, we suggest it is not only the structural modularity and standard interfaces that enable system evolution; but, it is also the relative interdependency of the modules. In short, PMs need to be mindful of the degree of change in subsequent increments/spirals. One subsystem is likely to affect another in the short- or long-run. And, that can make product evolution problematic. As Norman Augustine once said, "No change is a small change"; to convey that independent subsystems, even redundant ones, aren't always independent (Augustine, 1997).

PRODUCTION QUANTITY

Many might correlate the applicability of evolutionary development with long production runs. But we have also collaborated with officials from NASA who have said, "No two identical spacecraft are the same," which seems to contradict any idea that like configurations are a necessity among small production lot sizes (Roy, 2006). Indeed, naval shipbuilders voice the same about variation among individual ships, or within flights, of the same class. And even one-of-a-kind, nearly immutable projects like skyscrapers and bridges can be later remodeled and refitted, as discussed earlier. Aside from truly singular efforts, we have not yet found any universal evidence of an evolutionary approach being more or less suitable according to quantity of systems produced.

Recommendations for Practice

Project managers need to be aware of the inherent risks of evolutionary development and take necessary precautions to balance those risks. Many tools and control measures are developed and available to assist project managers in balancing the risks, such as TRLs, technical performance measurement, technical reviews, modeling and simulation, real options, project phasing, risk management, configuration management, earned value management, and organizational design.

Incremental development projects require steps to alleviate risks that may be inherent in the program structure. These include decisions about the number and concurrency of development increments and their scope and impact on the organization staffing.

Product attributes may help determine the suitability of evolutionary development. PMs should consider characteristics such as: mutability, time criticality, man-rating, modular interdependency, key parameters of capability vs. range of requirement attainment (i.e., binary vs. continuous), and the relative amounts of modular interdependency in the system architecture.

Rigorous configuration management accountability must be assigned and maintained for supportability, reliability, failure mode identification and causality, and to prevent the variety generated by EA from reducing total product performance.

Conclusions

Dr. Barry Boehm's recent book (2004) on software development advocates balancing disciplined (more rigid) and agile (more flexible) methods to capitalize on the benefits of both. Discipline is needed as a control mechanism to avoid risk, but agility is needed to respond quickly to customer needs. Saying, "One size fits all is a myth," he advocates a balanced approach based upon risk. Consistent with our findings, he also advocates more disciplined, risk-averse approaches for projects that are mission/safety critical, larger in size, and have more stable requirements.

It could be summarized that evolutionary development was at its inception, and is at its extension, all about risk. Paradoxically, it is an agile method envisioned to reduce risk and yet can potentially add its own. On the one hand, a spiral or incremental approach allays risk by reducing scope to render only the highest priority capabilities with the exclusive use of mature technology; and obtains early and continuous feedback from the environment for follow-on developments. On the other hand, it introduces concurrency during advanced development and adds variety in production, with all their attendant management challenges.

We have suggested that a one-size-fits-all methodology for DoD system development may not be appropriate, and we have offered for consideration several product attributes that might help determine the applicability of agile approaches. We speculate that evolutionary development may serve better than single-step development for initial capability when products are mutable, time-critical, non-maintenance-intensive, and have continuous (vs. binary) or uncertain requirements, short cycle-times (less knock-on effects), sequentially phased development blocks, and modular independence. In contrast, evolutionary development may not be as suitable when there are product safety or man-rating concerns and attributes opposite to those discussed here. In particular, PMs should understand the nature of their product requirements with regard to their range of attainment and relative to key parameters of capability and vis-à-vis the readiness level of their enabling technologies. Some key features may indeed be binary, and others may have significant ramifications of partial attainment—such as propagated change across the entire product componentry (as in weight reduction) vs. a more independent modular modification.

Variety can be both an asset (for end-users) and a liability (for manufacturers, owners, and supporters). As such, to compensate for product variety risk, we posit that acquirers must "own" the design and emphasize configuration management, keeping or assigning responsibility for that function and maintaining accountability for it (i.e., explanation of how assigned functions are being met).

Our title—"from amorphous to defined"—alludes not only to product specification, but also to risk realization in evolutionary development. PMs must be aware it has inherent challenges, both strategic and tactical; they

must balance them with tools that we have mentioned. In this article, we have both highlighted and illustrated them, as well as showing that incremental and spiral development can indeed work well—especially for technically mature and mutable products with open or elegant architecture.

Finally, stability is the quest in all things programmatic: for funding, requirements, design, production configuration, etc. But in an unstable world, and with the future filled with uncertainty, the only constant is likely to be change, and tension between control and change is probably unending. PMs do have some tools for coping, and being forewarned is forearmed. Successful use of these tools to balance control and risk in projects with a high rate of change and concurrency is an area for further research, to improve both our understanding and use of evolutionary acquisition.

Author Biographies

COL John T. Dillard, USA (Ret.), managed major weapons development efforts for most of his 26-year career in the military. He is now a senior lecturer with the Graduate School of Business and Public Policy at the U.S. Naval Postgraduate School in Monterey, California. COL Dillard is also a 1988 graduate of the Defense Systems Management College.

(E-mail address: jtdillard@nps.edu)

Dr. David N. Ford is an associate professor in the Zachry Department of Civil Engineering, Texas A&M University. In addition to teaching, he researches development project strategy, processes, and resource management. Dr. Ford earned his doctorate from Massachusetts Institute of Technology and his master's and bachelor's degrees from Tulane University. He has over 14 years of engineering and project management experience in industry and government.

(E-mail address: DavidFord@tamu.edu)

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WHAT PERFORMANCE BASED LOGISTICS IS AND WHAT IT IS NOT—AND WHAT IT CAN AND CANNOT DO

Bill Kobren

Although *Performance Based Logistics (PBL) sustainment* strategies have been used successfully for the last decade, misperceptions persist. This article discusses what PBL is and is not; and what it can and cannot do for the military services, program managers, and ultimately the warfighter. PBL is not about contractors on the battlefield or outsourcing organic workload. It is about weapon system performance, readiness, best value outcomes, capability, and effective and efficient warfighter support. PBL represents a fundamental change in how DoD supports its weapon systems and ensures those systems are reliable, maintainable, and available when and where the warfighter needs them. When it comes to delivering performance outcomes: PBL works.

Keywords: *Performance Based Logistics (PBL), Performance Based Life Cycle Product Support, Sustainment, Product Support*

image designed by Kay Sondheimer »

PBL

Perfomance | Based | Logistics

Performance Based Logistics (PBL) is a strategic readiness imperative. As a weapon system sustainment strategy, it is an integral mechanism by which the Department of Defense (DoD) seeks to break the stranglehold of the "death spiral," which former Under Secretary of Defense for Acquisition, Technology, and Logistics, Dr. Jacques Gansler, warned of in his testimony to Congress earlier this decade.

> Our equipment is aging. We cannot replace much of that equipment in the near future. Consequently, our Operations and Maintenance [O&M] costs will continue to escalate. This results in reduced readiness—yet at increasing costs. And, unless we reverse the trend quickly and deliberately, we face what I have described as a "death spiral"—a situation where reduced readiness requires us to keep removing more and more dollars from equipment modernization and putting it into daily O&M, thus further delaying modernization, causing the aging equipment to be over-used, further reducing readiness, and increasing O&M—a vicious circle. (Gansler, 2000, p. 68)

SUCCESSFUL PBL SUPPORT STRATEGIES REPRESENT A WIN-WIN-WIN FOR THE WARFIGHTER, ORGANIC SUSTAINMENT ORGANIZATIONS, AND INDUSTRY PARTNERS.

By leveraging long-term performance based agreements and incentivizing desired outcomes using a well-crafted set of metrics, PBL can deliver substantial performance improvements for both new and legacy weapon systems over traditional "spares and repairs" sustainment models. Moreover, when these strategies are properly implemented, the resultant outcomes can often be achieved at a lower cost than otherwise attained through more traditional sustainment approaches.

Despite the fact PBL support and sustainment strategies have been successfully used by the department for almost ten years, however, misperceptions persist within the DoD acquisition, logistics, and sustainment communities as to exactly what this thing called PBL is all about. This article will qualitatively examine a range of documentation on the subject in an attempt to clarify what PBL is and is not, and perhaps just as importantly, what it can and cannot do for the department, the military services, the weapon system program manager, and ultimately the warfighter; additionally, it will examine some of the key strategic implications for the DoD logistics and sustainment community charged with supporting aging weapon systems in an increasingly austere budgetary environment.

What PBL Is

So what exactly is this thing called PBL? Simply put, PBL is:

FIRST AND FOREMOST, ABOUT SUPPORTING THE WARFIGHTER

PBL is about performance. It is about readiness. It is about enabling mission accomplishment and ensuring the warfighter has weapon systems that are available, reliable, and supportable when and where required.

A WEAPON SYSTEM SUPPORT STRATEGY

As stated in the *Defense Acquisition Guidebook,* "Performance Based Logistics (PBL) is DoD's preferred approach for *product support* implementation (*DAG*, 2006, p. DAG-196). Succinctly, PBL is defined as "the purchase of support" as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapon system through long-term support arrangements with clear lines of authority and responsibility" (*DAG*, 2006, p. DAG-196).

DoD POLICY

"PMs [Program Managers] shall develop and implement performance based logistics strategies that optimize total system availability while minimizing cost and logistics footprint" (Department of Defense [DoD], 2008, p. 7).

FOCUSED ON PERFORMANCE OUTCOMES RATHER THAN DISCRETE TRANSACTIONS

Instead of relying on a traditional "spares and repairs" sustainment model, "the essence of Performance Based Logistics is buying performance outcomes" (*DAG*, 2006, p. DAG-197). It is procurement of a capability to support the warfighter vs. "the individual parts or repair actions" (*DAG*, 2006, p. DAG-197).

A FACILITATOR OF PUBLIC-PRIVATE PARTNERING (PPP) INITIATIVES

PBL support strategies "shall include the best use of public- and private-sector capabilities through government/industry partnering initiatives, in accordance with statutory requirements" (DoD, 2003, p. 7). Successful PBL support strategies represent a win-win-win for the warfighter, organic sustainment organizations, and industry partners.

AN IMPORTANT TOOL FOR MINIMIZING LIFE CYCLE COSTS

If properly implemented, with carefully constructed and clearly understood metrics, incentive structure, financial construct, and (if appropriate) contracting strategy, "Performance Based Logistics can help program managers optimize performance and cost objectives [including] through the strategic implementation of varying degrees of Government-Industry partnerships" (*DAG*, 2006, p. DAG-196).

TAILORABLE TO THE UNIQUE NEEDS OF EACH INDIVIDUAL PROGRAM

"Although the fundamental concept of buying performance outcomes is common to each PBL arrangement, the PBL strategy for any specific program or commodity must be tailored to the operational and support requirements of the end item" (Defense Acquisition University [DAU], 2005a, p. 2-4). "There is no one-size-fits-all approach to PBL. Similarly, there is no template regarding sources of support in PBL strategies. Almost all of DoD's system support comprises a combination of public (organic) and private (commercial) support sources" (DAU, 2005a, p. 2-4).

FOCUSED ON BEST VALUE, INCLUDING, BUT NOT NECESSARILY LIMITED TO LOWEST COST

"Finding the right mix of support sources is based on best value determinations of inherent capabilities and compliance with statutes and policy. This process will determine the optimum PBL support strategy within the product support spectrum, which can range from primarily organic support to a total system support package provided by a commercial Original Equipment Manufacturer (OEM)" (DAU, 2005a, p. 2–4). The exact definition of what actually constitutes a best value support solution often varies from program to program, but along with a cost component, frequently will also include some combination of performance, capability, skills, infrastructure, flexibility, quality, reliability, integration, and maintainability, among other components. Successful achievement of these best value outcomes is largely determined by the metrics and incentives identified in the PBL product support strategy.

What PBL Is Not

Conversely, there are also some things PBL cannot claim to be. For example, PBL is not:

A NEW CONCEPT OR A "FLAVOR OF THE MONTH" INITIATIVE

The roots of DoD PBL policy date back more than a decade, articulated in Section 912(c) of the National Defense Authorization Act (NDAA) for FY 1998, and the April 1998 *Secretary of Defense Report to Congress: Actions to Accelerate the Movement to the New Workforce Vision* in response to Section 912(c) of the NDAA for FY 1998. This report formed the basis for the July 1999 *Product Support for the 21st Century: Report of the Department of Defense (DoD) Product Support Reengineering Implementation Team Section 912c*; the September 2000 *Product Support for the 21st Century: A Year Later*; and the November 2001 *Product Support for the 21st Century: A Program Manager's Guide to Buying Performance.* PBL guidance was codified in the May 2003 DoD Directive 5000.01, *The Defense Acquisition System*, and DoD Instruction 5000.02, *Operation of the Defense Acquisition System*; and supported by detailed implementation guidance contained in Chapter 5 of the *Defense Acquisition Guidebook* (*DAG*) in 2006, issuance of *Performance Based Logistics: A Program Manager's Product Support Guide* in March 2005, and numerous related Office of the Secretary of Defense (OSD) and Service policies, instructions, regulations, and guidebooks. At OSD direction, DAU also created a series of PBL-related learning assets, including Continuous Learning Module (CLM 011) Performance Based Logistics (PBL); LOG 235A (now LOG 235) Web-based PBL training; LOG 235B (now LOG 236) case-based classroom PBL training; and establishment of the Web-based PBL toolkit (https://acc.dau.mil/pbl) in 2005.

In October 2005, "consistent with the Defense Business Board recommendation to leverage DAU to accelerate PBL implementation and to establish a DoD PBL Center of Excellence" (DAU, 2005b, p. 1), the Assistant Deputy Under Secretary of Defense, Logistics Plans and Programs designated DAU as a PBL "Center of Excellence" (DAU, 2005b, p. 1), to expand PBL learning assets, performance support, workshops, rapid deployment training, and "serve as a nexus for information cross-flow, liaison, and interface between and among the DoD components, the Defense Industry, and other Academic institutions on PBL applications and thought leadership" (DAU, 2005b, p. 1). In fact, the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) was so serious about PBL success, that the under secretary established an annual DoD-level awards program in 2005 to recognize outstanding system, sub-system, and component-level PBL strategies across the DoD. This compendium of policies, guidance, initiatives, training structures, and program recognition attests to the fact that PBL is clearly not a passing fad.

OUTSOURCING OR CONTRACTOR LOGISTICS SUPPORT (CLS)

To repeat: PBL is not synonymous with outsourcing or contractor logistics support. This is clearly articulated in the new December 2008 *DoD Instruction 5000.02*: "PBL offers the best strategic approach for delivering required life cycle readiness, reliability, and ownership costs. *Sources of support may be organic, commercial, or a combination* [emphasis added], with the primary focus on optimizing customer support, weapon system availability, and reduced ownership costs" (p. 29). While a majority of successful PBL Product Support Integrators (PSI) are in fact industry partners (and in many cases, the OEM), contrary to popular misconception, there is no mandate in DoD policy to use a commercial sector PSI, or even use an industry product support provider (PSP). "Part of the reason for this [mis]perception is that contractors have been effective and integral to most of the PBL strategies employed to date. PBL has not significantly changed DoD's reliance on contractors; it has only changed the nature of how we use their services" (Fowler, 2009, p. 10).

In reality, PBL optimizes the best public- and private-sector competencies "based upon a best-value determination, evidenced through a business case analysis (BCA), of the provider's product support capability to meet set performance objectives" (*DAG*, 2006, p. DAG-197). This, as expressed in the following excerpt from the *Defense Acquisition Guidebook*, is absolutely critical to understand:

> This major shift from the traditional approach to product support emphasizes *how program manager teams buy support, not who they buy from* [emphasis added]. Instead of buying set levels or varying quantities of spares, repairs, tools, and data, the focus is on buying a predetermined level of availability to meet the warfighter's objectives. (*DAG*, 2006, p. DAG-197)

While the authors of the *Defense Acquisition Guidebook* Chapter 5 could arguably have avoided confusion by choosing a different word such as procure or obtain, rather than 'buy', it is a fact that "effective PBL requires balanced contribution by both public- and private-sector providers" (Fowler, 2009, p. 10).

A PANACEA

PBL will not overcome a lack of sustainment planning, make up for an absence of effective program systems engineering, succeed with inadequate funding, mitigate the effects of poor leadership, or deliver instantaneous results. "PBL can often improve reliability, but there are limitations, particularly on legacy systems. Long-standing, systemic reliability problems in fielded systems are unlikely to be corrected without appropriate commitment of necessary funding" (L. Garvey, personal communication, November 27, 2008). The key is to establish

solid, well crafted, integrated metrics and incentives emphasizing the desired performance outcomes, most notably (but certainly not limited to) readiness, reliability, availability, maintainability, cost, and obsolescence/Diminishing Manufacturing Sources and Material Shortages (DMSMS) mitigation. To use a baseball analogy, DoD program managers and life cycle logisticians alike must recognize that ignoring early logistics design influence opportunities cannot be rescued by a PBL "diving basket catch" at the eleventh hour.

APPROPRIATE FOR EVERY SYSTEM

In some instances, particularly for legacy systems approaching retirement, PBL may in fact not be the most appropriate support solution. In other instances, the organic sector may be unable to effectively or efficiently support a system or the commercial sector may be unwilling to invest in such a strategy, judging the risks to be too great or the returns to be too inadequate. Only through a well-crafted, program-specific, and periodically updated business case analysis process can the program manager confidently make this determination.

STATIC

PBL policies, best practices, implementation strategies, and training continue to evolve as DoD and industry better understand the successes, challenges, obstacles, and issues related to PBL implementation and execution. New policy guidance was issued in a July 2008 policy memorandum by the USD(AT&L), for example, which states:

> For several years, acquisition and sustainment management [has] been appropriately focused on performance-based strategies. DoD Directive 5000.1 currently recognizes performance based logistics (PBL) as a key policy principle. I direct the Secretaries of the Military Departments to continue this emphasis *with a more precise orientation on life cycle product support* [emphasis added]. PBL offers the best strategic approach for delivering readiness, reliability, and reduced ownership costs. All of the policies and directions discussed in this memorandum are enabled by effective PBL implementation. I want to emphasize that PBL is not a contracting strategy—it is indeed a strategy applicable to both private sector and DoD organic providers. To facilitate effective PBL implementation, I direct the DUSD (L&MR) [Deputy Under Secretary of Defense, Logistics and Materiel Readiness] to reflect appropriate procedural strengthening in the *Defense Acquisition Guidebook*. I further direct that all MDAPs [Major Defense Acquisition Programs] reflect PBL implementation approaches in Life Cycle Sustainment planning. (Young, 2008, p. 3)

Newly issued DoD Instruction 5000.02 language reiterates the shift in focus from (performance based) logistics to (performance based) life cycle product support, stating:

> The PM shall work with the user to document performance and sustainment requirements in performance agreements specifying objective outcomes, measures, resource commitments, and stakeholder responsibilities. The PM shall employ effective *Performance Based Life Cycle Product Support* (PBL) planning, development, implementation, and management. Performance Based Life Cycle Product Support represents the latest evolution of Performance Based Logistics. "Both can be referred to as "PBL." (DoD, 2008, p. 29)

Further emphasizing how PBL policy and practices are not static, DoD policy makers established a Product Support Assessment study team in September 2008 (DUSD[L&MR], 2008), assembling participants from across the department to examine what a next generation PBL arrangement might look like; in particular, should the PBL business model be refined? In light of current economic and DoD budget pressures, life cycle cost reductions will very likely continue to be of paramount interest in the next evolution of the PBL business model.

(NECESSARILY) A TWO-LEVEL (ORGANIZATIONAL-TO-DEPOT) MAINTENANCE STRATEGY

The operative word here is "necessarily." While many successful PBL arrangements leverage, facilitate, or encourage a two-level maintenance strategy, a two-level maintenance strategy is not a requirement for, a definition of, or synonymous with a PBL support strategy. In fact, "many PBLs effectively (sustain) and enhance systems supported with three levels of maintenance" (L. Garvey, personal communication, November 27, 2008). This is particularly true for PBL strategies implemented for previously fielded legacy systems, which were very often developed years or even decades ago with a three-level maintenance strategy that included an intermediate level back-shop maintenance requirement.

What PBL Can Do

So what exactly can PBL do for a weapon system program manager and his or her staff? PBL can:

DELIVER HIGHLY EFFECTIVE SYSTEM, SUB-SYSTEM, OR COMPONENT SUSTAINMENT

"Performance Based Logistics, a strategy for making sure warfighters have the equipment they need when they need it, (quite simply) works. Government, industry and academic studies show PBL contracts regularly improve availability 20–40% and (reduce) costs by 15–20%" (Miller, 2008, p. 78). PBL delivers results. VADM Walter Massenberg, Naval Air Systems Command (NAVAIR) Commander clearly reiterated this point in a February 2007 memo entitled "PBL Guidance and Best Practices" where he categorically stated that "the success of Performance Based Logistics (PBL) has allowed the Naval Aviation Enterprise to improve support to the warfighter and achieve weapon system readiness at lower life cycle costs" (Massenburg, 2007, p. 1).

INCENTIVIZE DESIRED BEHAVIOR

Both NAVAIR and Naval Supply Systems Command (NAVSUP) have experienced substantial success in implementing PBL arrangements. Their philosophy is simple: The Navy buys [a] comprehensive performance package… not individual parts. This approach totally reverses [the] vendor incentive. Fixed price "pay for performance" contracts motivate [the] vendor to reduce failures/consumption, [while] a long-term commitment enables [the] vendor to balance risk versus investments. [This in turn] improves parts support (Material Availability increases and Logistics Response Time [LRT] decreases, resulting in improved readiness); optimizes depot efficiency by reducing Repair Turn Around Times (RTAT), Awaiting Parts (AWP), and Work in Process (WIP); [incentivizes] investments in reliability, [resulting in] Mean Time Between Failures (MTBF) [improvement]; and shortstops failures [in turn] reducing off-station demand (Garvey, 2004).

HELP THE PM STREAMLINE SUPPORT STRATEGY DEVELOPMENT

Randy Fowler (2009) described the properties of PBL in their most fundamental sense:

> PBL, with its outcome-focused principles, metrics, and incentives, serves as a simplifying strategy for the PM. PBL offers a one-stop approach for the PM to perform effectively as the life cycle manager. PBL is the best enabler of the total life cycle systems management concept; it provides

> a means for the resource-constrained program management office to develop, implement, and manage the sustainment of a system over its life cycle. (p. 12)

BE APPLIED FLEXIBLY DEPENDING ON A PROGRAM'S UNIQUE NEEDS

Application of "Performance Based Logistics strategies may be at the system, subsystem, or major assembly level depending on program unique circumstances and appropriate product support strategy analysis" (*DAG*, 2006, p. DAG-177).

SERVE AS A CRITICAL TOOL IN THE TOOLKIT FOR PROACTIVELY MITIGATING DMSMS AND OBSOLESCENCE ISSUES

> PBL offers an effective way to deal with obsolescence throughout the life of a product. Unlike traditional approaches to modernizing legacy systems, PBL holistically manages the product support of weapon systems, assemblies, subassemblies, and components. As the point of responsibility for meeting performance requirements, as outlined in the Performance Based Agreement, shifts to the Product Support Integrator (PSI) under the Program Manager, PBL provides a powerful tool for mitigating obsolescence and making continuous modernization (CM) a reality for current weapon systems, assemblies, subassemblies, and components (where a PBL application is feasible). PBL clearly fulfills the need for CM and obsolescence mitigation. (DoD, 2006, p. 2-1)

SERVE AS AN IMPORTANT ENABLER OF AN EFFECTIVE, END-TO-END SUPPLY CHAIN

"Performance Based Logistics enables the program manager to exploit supply chain processes and systems to provide flexible and timely materiel support response during crises and joint operations" (*DAG*, 2006, p. DAG-184).

> A Supply Chain Management (SCM) strategy is critical to the success of any PBL effort. Materiel support is a critical link in weapons systems supportability....Supply chain management includes the distribution, asset visibility, and obsolescence mitigation of the spare parts. From a warfighter's perspective, transportation and asset visibility have a substantial impact on high-level metrics and should be emphasized in the PBL strategy. (DAU, 2005a, pp. 3-7, 3-8)

POWERFULLY INCENTIVIZE THE WEAPON SYSTEM PSI TO INVEST IN MAJOR RELIABILITY, AVAILABILITY, AND MAINTAINABILITY INITIATIVES

Substantial improvements in system and subsystem reliability, time-on-wing, and operational availability have been seen on a variety of programs which have implemented PBL support strategies.

> PBL inherently self-motivates service providers to do "good things," such as improve component and system reliability, since it provides the foundation for increased profit. However, this motivation must be balanced against the ability of the service provider to invest in the needed infrastructure and processes required to achieve reliability improvements. (DAU, 2005a, p. 3-10)

What PBL Cannot Do

On the other hand, however, PBL cannot be all things to all people (or all programs). It cannot, for example:

OVERCOME POOR SUSTAINMENT PLANNING, LACK OF ADEQUATE TRAINING, OR A MISREPRESENTATION OF WHAT PBL IS

Kate Vitasek and Steve Geary (2008) examined the reasons why some managers fail to implement PBL successfully and came to the following conclusion:

> Most thought leaders agree that the PBL business model works, but not all programs have lived up to the success they hoped to achieve. Why is this? Many point to poor application of the PBL concepts.
>
> A report of the Acquisition Advisory Panel sums it up best: 'When individuals without the proper training and experience attempt to implement a performance-based contract, the results are understandably and expectedly poor…there is trouble consistently implementing it by an inconsistently trained workforce. (p. 64)

RELIEVE THE PROGRAM MANAGER OF HIS OR HER RESPONSIBILITIES AS LIFE CYCLE MANAGER FOR THE SYSTEM

"The Program Manager [is] charged with responsibility for supporting the entire system….The scope of support accountability for a PM never varies—they are responsible for supporting the entire system" (Cothran, 2007, p. 3).

Conclusions

In conclusion, it is important to understand what PBL is and is not. Additionally, while there are many things PBL can and cannot do, it remains firmly entrenched as a major initiative and part of the acquisition process. Randy Fowler (2009), in an article published in the Defense Acquisition University's *Defense AT&L* periodical, made the case for PBL's contribution to the acquisition process:

> The evidence is clear: PBL works. PBL delivers dramatic improvements in performance with lower operating costs across the total life cycle. PBL does more for the warfighter with less from the taxpayer. Instead of paying for transactional activities, the government and industry partners deliver improved performance at lower costs. (p. 13)

At the end of the day, PBL is not about contractors on the battlefield, outsourcing, degrading organic workforce expertise, or taking workload away from organic maintenance depots. It is about weapon system performance. It is about readiness, best value outcomes, capability, and providing effective and efficient support for the warfighter. PBL represents a fundamental change in how DoD supports its weapon systems and ensures those systems are reliable, maintainable, and perhaps most importantly, available when and where the warfighter needs them, in the most cost-effective manner possible. Ultimately, this is what PBL can—and must continue to do—for our warfighters and our nation.

Author Biography

Mr. Bill Kobren is the Defense Acquisition University Logistics and Sustainment Center director. He is responsible for DAU logistics courseware and serves as Life Cycle Logistics Functional Integrated Product Team executive secretary. He is Level III certified in Life Cycle Logistics and is a Certified Professional Logistician, with a master's degree from the Industrial College of the Armed Forces. This article was a 2009 Secretary of Defense National Security Essay Contest Semifinalist Award winner.

(E-mail address: bill.kobren@dau.mil)

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JOINT ACQUISITION COMMAND DOCTRINE —A SUCCESS STORY

Al Borzoo, Constance S. Short, Ken Brockway, and Col Stan L. VanderWerf, USAF

In the past, war planners typically treated acquisition as an afterthought. Operations Iraqi Freedom and Enduring Freedom Joint Task Force commanders were not initially afforded the full value of *acquisition capabilities* to buy local resources and manage the exploding number of contractors in the Area of Responsibility (AOR). Recognizing this shortfall, DoD created the *Joint Contracting Command* (JCC). The JCC provided substantial contracting capacity and coordination—critical attributes to effective, efficient AOR operations. This research and resultant report, originally prepared in 2006 for the Industrial College of the Armed Forces, played a substantial role in shaping joint thinking, culminating in creating Joint Publication (JP) 4-10, *Operational Contract Support*. JP 4-10 establishes long-needed *joint contracting* doctrine for Combatant Command AOR operations.

Keywords: *War Planning, Joint Contracting, Acquisition Capabilities, Joint Contracting Command, Joint Publication 4-10*

WAR PLANNING

Joint Acquisition Command Doctrine —Yes It's Needed!

"The Department's Total Force—its active and reserve military components, its civil servants, and its contractors—constitutes its warfighting capability and capacity."

Quadrennial Defense Review Report, 2006, p. 74

In today's fast-moving military environment, contractors have become critical to Joint Task Force (JTF) operations. As a result, contract management increased in complexity and scope requiring robust Department of Defense (DoD) management to maximize the effectiveness and efficiency of local material procurement and the contractor's support to the mission.

As operations in Iraq were to prove, insufficient contractor support planning placed great strains on the United States' ability to manage its contractors. While contracting efforts were ultimately successful, insufficient contract management capacity and coordination led to substantial efficiency losses and a reduction in effectiveness.

In recognizing these deficiencies, a Joint Contracting Command (JCC) with Joint Service participation and theater-wide responsibility was created for managing contracting efforts. However, doctrine did not exist for such an organization. Identifying this shortfall and in an attempt to address these deficiencies, we conducted research to examine the feasibility of establishing joint contracting doctrine for Combatant Command Area of Responsibility (COCOM AOR) operations. Along with this research, we submitted a report to the Industrial College of the Armed Forces in 2006 that proposed codification of joint contracting doctrine to permanently capture JTF lessons learned and ensure adequate deliberate contract planning for Operational Plans (OPLANs) and Contingency Plans (CONPLANs). The report proposed a full range of acquisition processes to accommodate the increasing workload of contractors in the AOR.

We also submitted the report to the Joint Staff in 2006, where the J-4 offices took great interest in our recommendations for joint doctrine. On October 17, 2008, Joint Publication 4-10, *Operational Contract Support*, was officially published (JCS, 2008). JP 4-10 addresses every concern presented in our report, places in doctrine almost every recommendation from our research, and reaches even further into a *war planning* option only recently applied on the battlefield during Operations Iraqi Freedom and Enduring Freedom: making maximum use of contractors on the battlefield.

The success of our efforts validated our research and reinforced a professional ethos to which we believe acquisition practitioners and professionals would do well to adhere: *If you suspect that an activity, task, or policy is not correct, then you should take action. Investigate it, write about it, and have the fortitude to make changes.*

PAST JTF CONTRACT PLANNING

In JTFs prior to and during Iraq, the Services brought their own contracting capabilities. Integration of the Service-let contracts, if it took place, was not by design. With increasing acquisition requirements placed on DoD for nontraditional reconstruction and stabilization operations as seen in Iraq, no one Service or agency initially had responsibility. Contracting officers often failed to use cost-effective local capabilities, opting instead for the Logistics Civil Augmentation Program (LOGCAP), even when local vendors served to reduce DoD logistics requirements (S. M. Seay, personal communication, January 24, 2006). At other times, the Services unknowingly competed against each other for local resources. These and other issues illustrated the need for an overarching acquisition strategy—one that would meet effectiveness and efficiency goals as well as policy requirements for the JTF. The Government Accountability Office (GAO) recognized this as a systemic problem as far back as the late 1980s. The GAO recommended DoD include contract management in all operations planning (GAO, 2004b, p. 5).

DOCTRINE PREVENTS REPEATING MISTAKES

The best reason for doctrine is to codify the lessons learned from past mistakes. The data collected for this study showed the DoD suffered from a lack of operational contracting doctrine during contingency and post-contingency operations at least as far back as July 1992, when the U.S. involvement in Bosnia began in the Balkans as part of humanitarian relief efforts (GAO, 2000).

Our research found the DoD learned and relearned these lessons at each major contingency despite the fact that lessons learned generated after each conflict demonstrated the need for doctrine. The case for doctrine was compelling (D. A. Scott, personal communication, January 4, 2006; C. M. Bolton, personal communication, January 19, 2009; S. M. Seay, personal communication, January 24, 2006; L. H. Thompson, personal communication, February 9, 2006; & M. J. Brown, personal communication, March 1, 2006). Joint Pub 4-10 also supports this assertion in its Introduction, which includes quotes from the 2006 Quadrennial Defense Review (QDR) and a U.S. Marine Corps statement of contractor support in World War II.

CORE RESEARCH RECOMMENDATIONS AND HOW THEY COMPARE TO JP 4-10

Our research, conducted at the Industrial College of the Armed Forces (ICAF) in 2006 for the Acquisition School, culminated in an 82-page report titled *Joint Acquisition Command Doctrine*. Using historical research, interviews, and other sources, it offered recommendations to codify joint contracting. At that time, our J-4 point of contact was tasked with initiating the development of Joint Doctrine for JTF integrated contracting. During our research, we held several meetings with action officer representatives from J-4, Joint Chiefs of

Staff (JCS). By mid-2007, a full draft joint contracting doctrine publication was under formal review. Of note, our report generated 26 recommendations for joint contracting doctrine—24 of which are found in JP 4-10. The following discussion pinpoints selected descriptions of our study's recommendations and how JP 4-10 addressed those concepts.

Single Integrative Process. Our report recommended a single integrative acquisition process within a JTF to allow an enhanced use of acquisition teams in-theater. This would assist in creating a critical mass of acquisition expertise, thus allowing the COCOM and JTF commander strategic unity and flexibility with respect to its contract support. With dispersed contracting organizations in Iraq, acquisition personnel were hard-pressed to devote time to strategic thinking due to a focus on daily tactical considerations. Functions such as resource allocation, balancing skill sets, program integration, and requirements prioritization suffered. As an example, U.S. Central Command (CENTCOM) replaced a task on the Air Force Contract Augmentation Program (AFCAP) with a theater-wide air traffic services contract. In Iraq, however, a different contract provided the service (D. A. Scott, personal communication, January 4, 2006), thus setting the stage for coordination issues that would have been simpler had a single contract been awarded. GAO also recognized these problems as stemming from a lack of coordination (GAO, 2005). We proposed a joint contracting activity provide a single integrative acquisition process to evaluate these disparities and provide the best acquisition strategy possible. This recommendation is a core tenet of JP 4-10.

An integrated approach would allow the joint contracting activity to pool resources and optimize acquisition decisions at critical points as required by the JTF Commander. This would present the opportunity to leverage specific skill sets to fulfill high-priority acquisition activities. In an interview with Maj Gen Darryl A. Scott, USAF, Joint Contracting Command's commander in Iraq, he stated, "There are other assets in-theater that could be used to balance workload to make sure high-priority and/or high-payoff work gets addressed" (D. A. Scott, personal communication, January 4, 2006). Former JCC Iraq Commander BG Steven Seay, USA (Ret.), also acknowledged this deficiency and recommended acquisition personnel, including contracting officers and other specialists, be consolidated into a single organization (S. M. Seay, personal communication, January 24, 2006). The annexes to our report recommended three integrated organizational constructs—one each for large, medium, and small task forces. Also in its annexes, JP 4-10 recommends three constructs: Service Component support to its own forces, a "Lead Service Theater Support Contracting Organization," and a "Joint Theater Support Contracting Organization."

Title 10 Authorities. Our report recommended the Services use their inherent Title 10 authorities to ensure resources and contracting authorities would be in place. Chapter 2, paragraph 7 of JP 4-10 describes the Service Title 10 authorities and how to use those authorities to enhance joint contracting activity.

Coordination Council. Our report recommended creation of a Coordination Council to enhance resource cooperation among the Services. Roughly analogous to the Coordination Council, JP 4-10 directs the establishment of the Combatant Commander Logistics Procurement Support Board (CLPSB) to deal with general policies and AOR-wide issues related to contracting support.

REQUIREMENTS GENERATION/PRIORITIZATION SUPPORT

We recommended in 2006, the JTF contracting command entity should have the authority to operate an acquisition review board on behalf of the JTF commander to collect and prioritize contracting requirements. Traditionally, a contracting or acquisition activity does not generate requirements. As happened in Iraq, however, the requiring activities, especially those responsible for stability and reconstruction, did not always have sufficient resources or time to integrate and prioritize requirements across the theater. Iraq's JCC filled in much of the gap with a relative degree of success. Therefore, a review board should have the flexibility to perform these functions as needed and provide recommendations to the JTF Commander or other supported customers. These recommendations would consider declared needs from the operators. Upon receipt of the customer's direction, the board would integrate requirements appropriately, develop acquisition strategies, and execute contracts.

JP 4-10 directs the creation of a Joint Acquisition Review Board (JARB) specifically to control requirements generation and prioritization. JP 4-10 also directs creation of a Joint Contracting Support Board (JCSB) for the purposes of assigning prioritized requirements to the best contracting activity. Our construct assigned this to the joint contracting authority without identifying a separate board to perform this task. In addition, our research supported the need to assign tasks to contracting entities, regardless of Service, to ensure balanced workload and matched skill-sets/workforce availability. JP 4-10 agrees, and in fact offers a better and more refined approach to our original recommendation in 2006.

Our proposed doctrine considered accommodation of coalition forces and interagency support for contingency and post-contingency (Phase IV) operations. JP 4-10 addresses interagency and coalition contracting needs extensively. Interagency and coalition support is a core tenet of JP 4-10.

Our study recommended contracting be embedded in COCOM planning with pre-designated, trained personnel deploying with a JTF to enable the combatant commanders to execute their acquisition missions effectively and efficiently (GAO, 2003). This is again a core tenet of JP 4-10. The document addresses COCOM and JTF planning considerations extensively.

Our doctrine proposal recommended COCOM authorities define unique roles and responsibilities to match the planning requirements for each JTF. We recommended the COCOM consider subordination of a contracting command

entity to the JTF leadership and OPCON of in-theater acquisition resources to the contracting command entity to improve insight, directive authority, integration, and adherence to strategic policies. JP 4-10 describes a similar position with directive roles and responsibilities, while leaving enough flexibility for the COCOMs to plan to their unique needs.

CONTINGENCY TO SUSTAINMENT

Our report, as part of planning strategy, recommended contracting activities transition from higher risk (contingency combat operations) to lower risk (sustainment) at appropriate times for the mission. In this transition, the contract type used should shift from cost plus (more risk on the government where speed and quality is critical) to fixed price (less risk on the government where cost efficiency grows in importance). When a contractor does not have highly variable costs associated with security protection, the U.S. Government has a healthier environment to competitively award firm fixed price (FFP) contracts and make better use of funding. In-theater acquisition expertise can best decide when to change the type of contract. For example, one of the reasons the Civilian Augmentation Program (CAP) contracts were so expensive was they were all flexibly priced—an appropriate view with a highly fluid operational environment. However, as parts of an operation stabilize, fixed price contracts generate better value (D. Scott, personal communication, 2006). JP 4-10 specifically mentions this strategy and identifies potential crossover points for changing contract strategies.

This concept, in our view, is critically important. The transition from contingency to sustainment contracting is necessary to improve the cost efficiency of operations over time. Joint Contracting Activity leadership can help provide JTF commanders appropriate strategies for the transition. At a minimum, a general transition concept added to deliberate planning will help with execution. The inherent flexibility offered by a CAP instrument comes at a premium; and at some point, the cost of that flexibility may not be necessary. In addition, commodity groups (water, food, construction materials, depot maintenance) may transition at different times and under different local conditions. Transition planning should allow for greater competition—a critical step as risks mitigate and cost becomes a greater consideration. JP 4-10, Chapter 8. Section C (3) specifically describes these considerations.

FAR/DFARS MODIFICATIONS

Our report recommended the Federal Acquisition Regulation (FAR) and Defense Federal Acquisition Regulation Supplement (DFARS) be reviewed and adjusted to better serve contingency and post-contingency conditions. For example, the security environment in Iraq drove many contracting officers to write cost contracts for Operations and Maintenance (O&M) funding. These contracts, however, typically required the U.S. Government to take ownership

of the material and/or facilities used by the vendor after the contract closed out. As physical goods accrued from the conduct of these contracts, property management became a substantial burden. Additionally, much of the equipment purchased was of limited value to the government. We recommended regulations consider more flexibility in funding thresholds, property purchase requirements, and solicitation timelines to eliminate or minimize these problems (D. A. Scott, personal communication, January 4, 2006). Others we interviewed supported the contention that the FAR and DFARS should either be changed or supplemented to ensure proper contingency guidance and authorities (C. D. Blake, personal communication, January 19, 2006, & A. B. Bell, personal communication, February 8, 2006). As such, we recommended in our report that each COCOM obtain specific advance regulation waivers for each plan as part of the planning process. These would activate automatically upon plan implementation. JP 4-10 chose not to give this authority to the COCOMs. However, it did place this authority with the Director, Defense Procurement and Acquisition Policy—a position reporting to the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. This is where authority to change DFARS for other tasks resides already, so the choice was obvious. JP 4-10 specifically enhances JTF operations by assigning this DFARS mod responsibility for operational contracting directly and clearly to this director.

OPERATIONAL AND STRATEGIC TRAINING

We recommended the doctrine establish training and exercise requirements to generate mature in-theater acquisition capacity, capable of meeting mission needs while operating in austere environments. We stated the doctrine should require that COCOMs consider broad skill sets for a joint contracting activity including contracting, program management, financial, legal, quality assurance, and information technology to meet contract management requirements in the AOR. The doctrine should call for "train the trainer" functions to aid in planned transition to host countries and identify who should pay for the required exercises. Appendix G of JP 4-10 describes broader skill sets and their importance, especially in the organizational construct for large JTF operations.

Our research led us to recommend COCOM and JTF staff acquisition training to help them understand how to best use acquisition capabilities for military and political objectives. For example, with a joint contracting activity providing unity of effort, acquisition capacity can be re-directed temporarily to meet higher JTF priorities. As such, an Air Force (AF) contracting officer could be tasked to contract for line haul to get ammo up to a heavily engaged Marine unit. The following month, when the AF needs contracting capacity to build an airbase, Army resources could temporarily augment AF contracting officers to support the requirement. Doctrine should specifically identify the organization responsible for conducting these training programs. To support political objectives, a JTF could improve a theater-wide strategy of contracting with local companies, thus putting local personnel to work. Joint Publication

4-10 provides extensive detail defining terms, describes contracting command authorities and structure (which is different than operational command structure), and offers the value and costs of contractor support in the AOR. In essence, JP 4-10 is the capstone-training document for COCOM and JTF staffs in the contracting area. As such, JP 4-10 fully incorporates our report's overall training recommendations.

IMPROVED SUPPORTING AGENCY ASSISTANCE

We recommended use of an in-theater contracting command entity to improve supporting agency assistance to the JTF. As an example, for Operation Iraqi Freedom (OIF), the Defense Contract Management Agency (DCMA) was administering a Stryker repair contract in Qatar that was generally meeting contract performance requirements. Meanwhile another contractor's up-armoring efforts were behind schedule, but DCMA had not received a delegation to work those issues (D. A. Scott, personal communication, January 4, 2006). DCMA's core mission is to help the DoD better manage contracts. In fact, DCMA did not receive delegations to several of the most challenging contracts, either at a quality assurance level or more extensively. A unified and coordinated effort expressed through a centralized contracting activity could better direct supporting agency assistance when and where needed. Adding contracting requirements into deliberate planning will force the COCOM to consider the best use of supporting agencies. The GAO had also recognized the lack of coordination as a systemic problem since the late 1980s (Waxman & Dingell, 2004, p. 5). JP 4-10 correctly defines many supporting agency missions and how they can specifically support COCOM and JTF commanders.

CARE AND FEEDING OF CONTRACTORS ON THE BATTLEFIELD

Contractors perform critical functions for JTFs but also need support. During OIF and other contingencies, contractor support requirements (housing, food, security, etc.) were not uniform, due at least in part because the contracts awarded from various agencies across the DoD did not benefit from authoritative COCOM guidance. The sheer number of contractors and various contracting instruments made it "virtually impossible to keep track of who eats for free and who must pay" based on the terms and conditions set forth in the contracts (D. A. Scott, personal communication, January 4, 2006). The DoD's response to this problem was to create an expensive and complex system of control. Unfortunately, as has happened in many cases in Iraq, this did not fully solve the problem and did not prevent many contractors from receiving services to which they were otherwise not entitled. With insufficient control of the contractors, some companies underperformed by using government support without reimbursement, whereas their contract required the vendor to pay for or separately provide those services. This created funding inefficiencies. JP 4-10

devotes much discussion to this topic and directs the creation of a Contractor Support Integration Plan (CSIP) designed specifically to fix these kinds of issues.

This type of COCOM plan is also critically important in using CAP contracts. For example, in the case with Iraq, Procurement Contracting Officers (PCO) for LOGCAP did not have sufficient guidance to determine how many contractors needed support, what type of support they needed, and whether it would be reimbursable (GAO, 2004b). This left CENTCOM, in the case of OIF, unable to plan LOGCAP support effectively because the huge number of contractors sent and specific status of each contract could not be determined on any given day. Without this information, the number of beds, meals, and support services needed was a difficult target to identify (D. A. Scott, personal communication, January 4, 2006; C. M. Bolton, personal communication, January 19, 2006; & S. M. Seay, personal communication, January 24, 2006). Again, JP 4-10 devotes a considerable amount of detail in describing how each of the Services runs their LOGCAP programs, thus laying the groundwork for averting or minimizing cost inefficiencies in this arena.

SUPPORT FOR A JOINT CONTRACTING ACTIVITY

In interviewing 19 personnel for our study, we found the following consistent views as shown in the appendix. Significantly, while differences in recommendations for contracting structure existed between the interviewees, most agreed on the need for joint doctrine, proper resourcing, and a central organization to control contract management in theater. Most also agreed planning and training were key considerations. Several of the interviewees also recommended LOGCAP and other contingency contracts be included in operations plans (C. M. Bolton, personal communication, January 19, 2006, & S. M. Seay, personal communication, January 24, 2006).

HEAD OF CONTRACTING AUTHORITY AND WARRANTS

In our study, we recommended Head of Contracting Authority (HCA) be resident in-theater in the Joint Contracting Activity. We also recommended as a best approach the issuing of warrants within theater. We find consistent recommendations, also in JP 4-10, which designate the HCA should reside in-theater. It also directs Senior Contracting Official assignment to the Joint Contracting Activity to issue warrants, also known as Certificates of Appointment, in-theater efficiently under a single policy.

CONTRACTING OFFICER OPCON

We also recommended, for unity of effort, all contracting personnel should be OPCON to the Joint Contracting Activity, although the affected personnel do not need to reside in a single location. Initially, when effectiveness is most critical, acquisition professionals need the latitude to operate co-resident with

their units and other agencies to meet mission requirements. This approach is less efficient but is more effective at supporting highly variable operations, the kind of operations most likely found at the beginning of contingency operations. OPCON relationships to a central authority are still possible in this environment, and will allow better flow of strategic-level acquisition advice, including the identification of existing and available contracting instruments. To support this, we specifically recommended using centralized control and decentralized execution for contracting, where guidance would come from a centralized authority but contracting officers would travel with their units and directly support their lower echelon commanders. The key to this strategy is the concept of centralized control and decentralized execution of contracting activity (Houglan, 2006, p. 25). The JP 4-10 does in fact use the same concept of centralized control and decentralized execution with an OPCON relationship to a centralized contracting authority.

Conclusions

History has shown the increasing importance of contractors on the battlefield. The scope and depth of their support made the integration of DoD and contractor operations essential for mission success. Prior to 2008, joint doctrine did not exist to codify the necessary lessons learned from previous experiences. Now with the publication of Joint Publication 4-10, *Operational Contract Support*, integration of contractors on the battlefield is squarely in joint doctrine with sufficient detail to prevent relearning lessons from previous operations.

Our report, written in 2006 for the Industrial College of the Armed Forces; research from many others; and a high measure of momentum and desire on the part of the Joint Staff and the Services were significant catalysts, culminating in the publication of JP 4-10. Twenty-four of the 26 recommendations from our 2006 report were incorporated into JP 4-10—some almost verbatim and others in highly variant versions of what we originally recommended.

Publication of the JP-4-10 represents diligent work on the part of the Joint Staff, going far beyond the parameters of our original report and providing much-needed depth and breadth to operational contracting considerations.

Finally, the privatization of some aspects of acquisition and contracting during warfare has led to many interesting and complex issues. For that reason, we want to encourage each of you, especially those who are not contracting officers and expect to deploy to a JTF/contingency location, to review JP 4-10 in its entirety.

Author Biographies

Mr. Al Borzoo, with 25 years of experience in DoD systems acquisition, is the Country Program Director for Germany and African Countries at the Navy International Programs Office in Washington, DC. He is responsible for establishing security assistance policies regarding Navy and Marine systems for Germany and all African Countries to meet their defense and humanitarian requirements. Currently, he manages over 200 programs valued in excess of $900 million.

(E-mail address: al.borzoo@navy.mil)

Ms. Constance S. Short is the deputy director of the Defense Contract Management Agency (DCMA), Tactical Wheeled Vehicles in Chicago. Ms. Short is responsible for managing over 260 civilian and military experts performing geographically dispersed DoD acquisition life cycle contract management for over 8,803 contracts valued in excess of $14 billion with over 925 contractors. Previously as the director, Combat Support Center, she managed the Agency's complex worldwide force deployments.

(E-mail address: connie.short@dcma.mil)

Mr. Kenneth "Ken" Brockway is currently deputy chief, Direct Support Office: Mission and Network Systems, Directorate of Information Assurance, National Security Agency (NSA), where he ensures systems security engineering support is provided to Department of Defense and Intelligence Community programs. Brockway joined NSA in August 2003 after retiring from the U.S. Air Force, where he served more than 31 years as a Communications-Electronics Officer.

(E-mail address: klbrock@missi.ncsc.mil)

Col Stan L. VanderWerf, USAF, is commander of the 542nd Combat Sustainment Group (CBSG) where he is responsible for development and sustainment of the U.S. Air Force's Electronic Warfare (EW) equipment. The 542 CBSG manages 67 EW systems, several development programs, and over 40 Foreign Military Sales cases. Col. VanderWerf has held scientist, engineering, program management, and contracting officer positions during his 26-year career, including two combatant commands and two overseas assignments. He is a distinguished graduate of the Industrial College of the Armed Forces.

(E-mail address: stan.vanderwerf@robins.af.mil)

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APPENDIX

LEVEL OF INTERVIEWEES' SUPPORT FOR THE CONCEPT OF A JOINT CONTRACTING ACTIVITY

Interviewee	Joint Doctrine	Planning	Resourcing	Training	Reference
Mr. Claude M. Bolton	x	x	x	x	January 19, 2006
LTG William E. Mortenson, USA	x	x	x	x	January 25, 2006
LTG David H. Petraeus, USA	x	x	x	x	January 4, 2006
Mr. Lee H. Thompson	x	x	x	x	February 9, 2006
Maj Gen Darryl A. Scott, USAF	x	x	x	x	January 4, 2006
MG John M. Urias, USA	x	x	x	x	October 24, 2005 (Briefing)
BG Steve M. Seay, USA	x	x	x	x	January 24, 2006
RADM Marty J. Brown, USN	x	x	x	x	March 1, 2006
Col Anthony B. Bell, USAF	x		x		February 8, 2006
Col Casey D. Blake, USAF	x		x	x	January 19, 2006
CDR William F. Reich, USN	x		x		February 10, 2006
CDR Forest. W. Browne, USN	x	x	x		January 25, 2006
LtCol Stephen Elliot, USMC	x		x		February 3, 2006
LtCol John E. Cannady, USMC	x	x	x	x	January 23, 2006
LtCol Mark A. Hobson, USMC	x		x		January 18, 2006
CDR Robert C. Cox, USN	x		x	x	February 2, 2006
COL Ainsworth B. Mills, USA	x	x	x	x	January 19, 2006
COL Stephen B. Leisenring, USA	x	x	x	x	February 9, 2006
COL Jacob B. Hansen, USA	x	x	x	x	February 6, 2006

Note: An "x" in any of the blocks signifies the interviewee specifically endorsed the need for Joint Doctrine, strategic planning, coordinated resourcing, and/or improved training. Significantly, most of the personnel interviewed for this article recommended planning to ensure proper allocation of resources to top JTF priorities. This is yet again a strong sign that practitioners in the field universally desired joint contracting operations doctrine. The clear recognition of the need for doctrine among contracting practitioners was undeniably helpful in supporting the creation of JP 4-10. The desire and momentum was certainly in place from 2006 to 2008, and the DoD took advantage of that momentum to create JP 4-10.

Kurdistan
Mosul
Tigris
Mesopotamia
Euphrates
Aleppo
Homs
Damascus
Syrian Desert
Baghdad
Al Jauf

APPLICATION OF SYSTEMS ENGINEERING TO RAPID PROTOTYPING FOR CLOSE AIR SUPPORT

John M. Colombi and Richard G. Cobb

Twenty-first century military operations have brought forth many new challenges for the Armed Forces of the United States. One such challenge is with new operating environments, where current systems are not always effective. While it is desirable to apply a *systems engineering* approach to best meet critical user needs, there may be a misconception that systems engineering requires a lengthy and detailed process not nimble enough for a rapid *prototyping* effort. This article describes how a classic systems engineering methodology was successfully tailored to the rapid development of potential material solutions to meet a critical operational need. Key observations are drawn from this experience and formulated into heuristics for tailoring systems engineering for future rapid prototyping efforts.

Keywords: *Systems Engineering, Prototyping, Rapid Product Development, Project Selection, Close Air Support*

image designed by Harambee Dennis »

FMD
Friendly Marking Device
Allowing JTAC to quickly and accurately identify friendly ground personnel.
Friendly
Personnel: Ground Personnel
Location: Lat: 38.448589
Long: 77.903889
Status: Under attack
CAS aircraft support: ENROUTE

Within the U.S. Air Force, a critical need has emerged for an added capability associated with the position of Joint Terminal Attack Controller (JTAC)—the Air Force airman trained to interface with aircraft to request and direct *Close Air Support* (CAS) attacks: to quickly pinpoint the location of friendly ground forces and communicate their location to CAS aircraft. Current operations in urban environments have placed JTACs in very close proximity to enemy forces and reduced the time to communicate with CAS assets. This close proximity and time compression, coupled with the complexity of the urban terrain, has made it difficult for the JTAC to direct an air attack using current systems and tactics while maintaining an acceptable fratricide risk. Thus, a Friendly Marking Device (FMD) that allows a JTAC to quickly and accurately identify the position of friendly ground personnel to CAS aircraft has emerged as a critical need.

Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering?

Systems engineering offers a rigorous and repeatable methodology for translating a critical need into a viable solution (Defense Acquisition University [DAU], 2001). However, the perception that it necessitates a lengthy and detailed process may contribute to a misconception that the benefits of systems engineering must be traded off to be able to respond quickly to critical user needs. This perception/misconception juxtaposes a key question: Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering?

This article attempts to answer that question by detailing an effort to tailor and apply systems engineering to a collaborative research project to rapidly prototype novel designs for the FMD. It describes the methods employed and offers key observations from the experience as lessons learned. From the lessons, heuristics are derived to guide the tailoring and application of systems engineering to future rapid prototyping efforts.

The JTAC user identified the critical need for a new way to mark the location of friendly ground forces. Under the auspices of the Air Force Research Laboratory (AFRL) Rapid Reaction Program—a program designed to match innovative research initiatives to critical needs—an effort began aimed at identifying and applying technology to the critical operational need, and resulting in the generation of a viable solution.

Method

PROJECT DEFINITION

The first step in defining the project was to assemble a core project team to guide the development effort. During this step, key stakeholders were identified—user/customer, project sponsor, systems engineers, and technology experts. The core team then worked to understand the operational need and, thereby, define the objective of the project: Develop, demonstrate, and transition a marking solution that enables a JTAC to establish a common point-of-reference with a CAS asset such that the CAS asset can attack an intended target while avoiding fratricide.

Constraining factors such as cost, schedule, technology maturity, resource availability, and operational limitations were clearly identified. Arguably, the most significant constraint on the project was a compressed schedule, inherent to the rapid reaction process. Driven by the desire to rapidly field a prototype, the project was constrained to 5 months. These constraints became fundamental elements driving several key evaluation and technical focus factors in our systems engineering process.

TAILORED APPROACH

After careful consideration of a variety of approaches, the classic Vee model described in Dennis M. Buede's (2000) text was tailored and selected as the basis for this project. Both the construct and execution of the model were modified to accommodate the constraints identified at the outset. The tailored Vee model (Figure 1) follows the general construct of the classic Vee model in that requirements solicitation and definition occurs down the left

FIGURE 1. TAILORED VEE MODEL

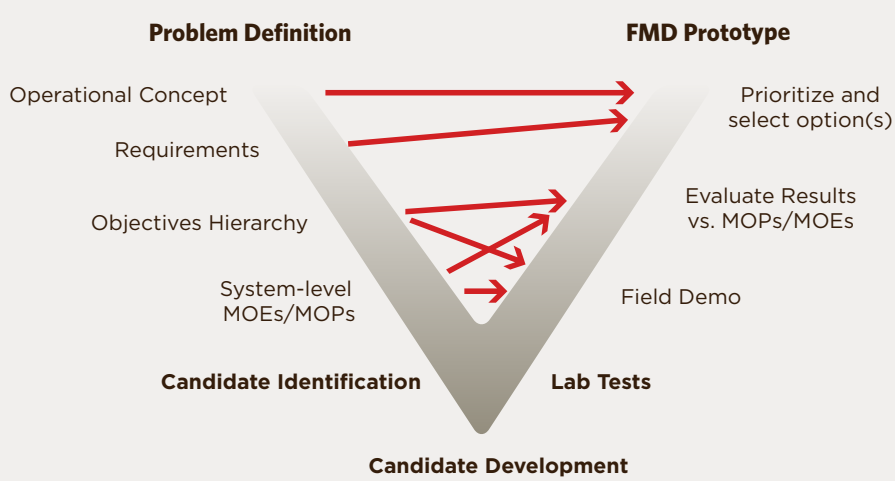


TABLE 1. SAMPLE USE CASE

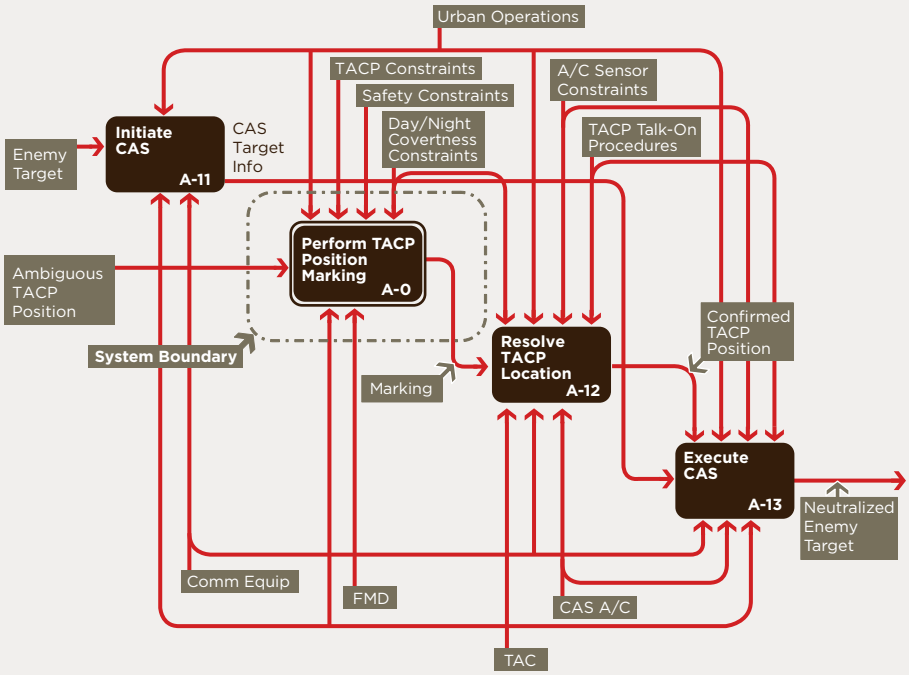
Urban Close Air Support Use Case	
Use Case Name	**Name:** Urban Close Air Support
	Brief Description: Describes the process directing a CAS attack in an urban environment.
Actors Involved	**Joint Tactical Air Controller (JTAC):** A certified servicemember who directs the action of aircraft engaged in close air support. • Goal—Accurately identify target and friendly forces to CAS aircraft.
	Close Air Support (CAS) Aircraft: Aircraft tasked to support close air support operations. • Goal—Accurately acquire target and friendly position.
	Air Support Operations Center (ASOC): The principal air control agency.
Preconditions	JTAC has communication with ASOC.
	JTAC has requested CAS support.
	CAS aircraft tasked to support the JTAC.
	CAS has aircraft in contact with JTAC.
Success Guarantee	CAS aircraft provide bombs on target.
	There is no fratricide of friendly forces.
	Collateral damage has been minimized.
Flow of Events	**Main Success Scenario:** Sequential, numbered steps to carry out the task.
Postconditions	**CAS Aircraft:** Provide bombs on target.

side (decomposition and definition), design engineering occurs at the vertex, and qualification occurs moving up the right side. An important element of tailoring as applied herein involves the recognition that the output of this tailored Vee model is not a validated system ready for use in the field. Rather it is an analytically tested and evaluated prototype that may be easily readied for production and, ultimately, used in the field.

PROBLEM DEFINITION

To state the problem in solution-independent terms, the definition process began by exploring the problem domain. After a literature search of typical CAS processes (Joint Chiefs of Staff, 2003; Pirnie et al., 2005), a set of elicitation questions was developed to help define a common understanding of the problem

FIGURE 2. EXTERNAL SYSTEMS DIAGRAM



with the user. These questions were then used as a basis for interviewing the user representative to build a definition of the problem.

It became evident the original problem statement did not capture another perspective that existed—that of the CAS pilot. To correct this, experienced CAS pilots were interviewed in a similar fashion to explore their perspective of the problem. After compiling the results of the interviews, the problem was stated as: The Joint Terminal Attack Controller (JTAC) lacks a covert means to quickly and accurately mark the location of friendly forces.

OPERATIONAL CONCEPT

The next step was development of the concept of operation for the solution—the vision of how the user might employ the resultant device. Borrowing from software engineering (Larman, 2004), the concept of a use case was employed to create a description of the sequenced actions that the user would likely follow in employing the FMD (Cockburn, 2001). Table 1 shows a simplified version of the basic use case for directing CAS attacks in an urban environment. (This is not a complete use case and is included for illustration only.)

Buede (2000, p. 144) states, "The single largest issue in defining a new system is where to draw the system's boundaries." As the project progressed, the value of defining and documenting the system boundary became evident, and

the External Systems Diagram shown in Figure 2 was developed. Creating the External Systems Diagram helped highlight the key interaction in the operational concept—the use of the FMD to establish a common point of reference between the JTAC and the CAS pilot.

Requirements

With the appropriate data from the informal interviews of the user and other stakeholders as guidance, the system requirements were derived in detail from the operational concept. Once the initial set of requirements was identified, it was validated with the user and other stakeholders. In addition, the user

TABLE 2. USER REQUIREMENTS

User Requirements with Weights		
Type	**Requirements**	**Weights (1-10)**
Environmental	Weather Limitations	9
	Day/Night Limitations	10
Physical	Waterproof	8
	Shockproof	8
	Power Source	8
	Weight	10
	Size Dimensions	10
Operational (Signal)	Signal Duration	10
	Signal Covertness	10
	Signal Field of View	7
	Signal Range	10
	Accuracy Resolution	10
	Signal Spectrum	10
	System Compromise	2
	Unique Signal	2
	Signal Delay	10
Operational (System)	Ease of Use	8
	Modification Required	8
	Unique Signal Display	2
Acquisition (Long-term)	Long-term Unit Cost	5
	Product Feasibility	8
Acquisition (Short-term)	Estimated Cost	5
	Prototype Availability	7
	System Maturity	7

and other stakeholders provided weights for each requirement to determine their priority. Table 2 shows a sample of the system requirements (without the associated values, but with user weights).

OBJECTIVES HIERARCHY

In making a decision or evaluation, the development of a value model (in this case, an objectives hierarchy) enables the systematic identification and application of user value to multiple attributes of a decision. Following the approach described by Ralph L. Keeney (1992), a set of appropriate objectives was identified. Attributes to measure the degree to which the objectives are met were also developed. Finally, a hierarchy defining the relative weighting of the objectives was created (Figure 3).

The use case and user-expressed desires and constraints served as inputs into the development of the hierarchy. The objectives were developed by

FIGURE 3. SAMPLE OBJECTIVES HIERARCHY

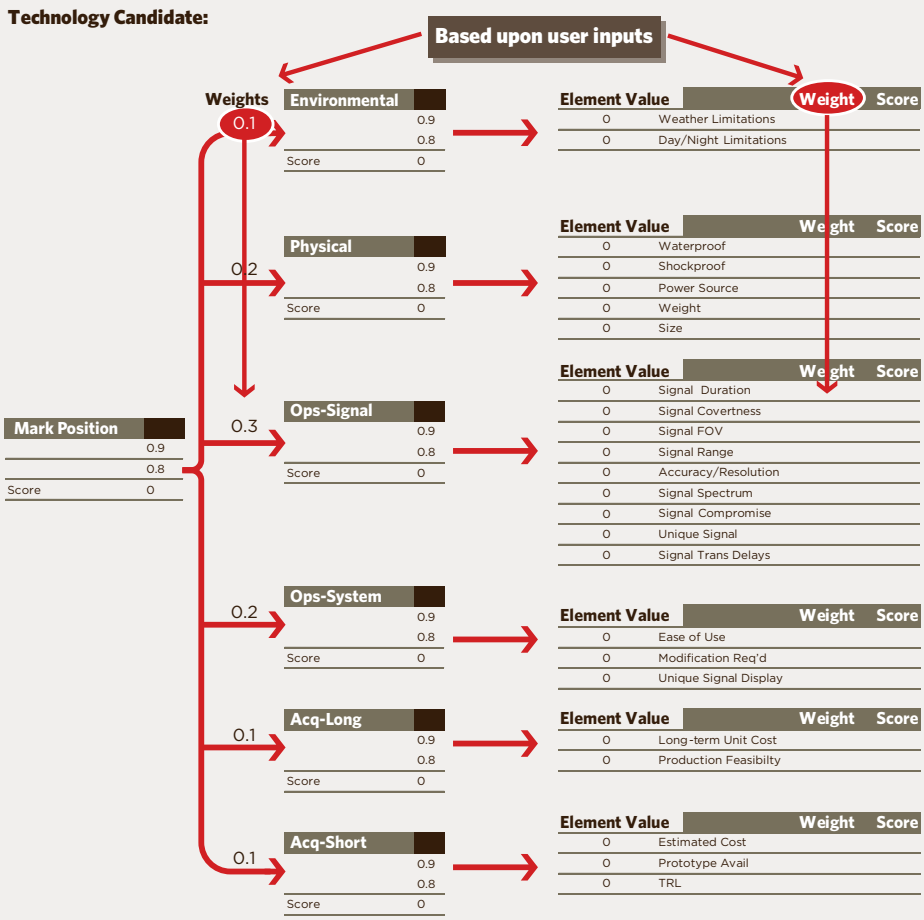
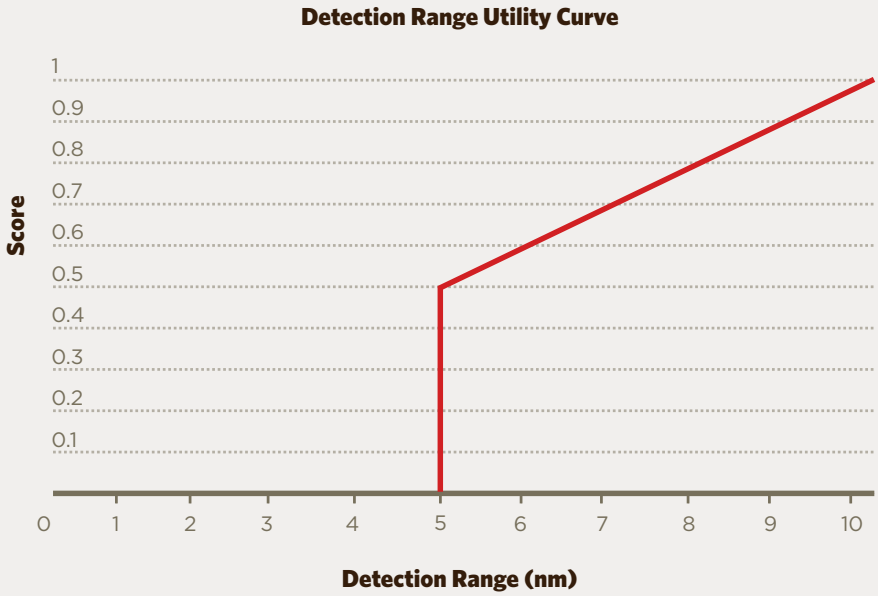


FIGURE 4. SAMPLE UTILITY CURVE



working closely with the user/customer. Once the basic hierarchy had been constructed, the user was solicited for the relative weightings that define the value or importance of each of the various objectives. Relative weights for applicable objectives were also solicited from the CAS pilots. Utility curves were produced based upon the information gleaned during the development of the problem definition and operational concept. Risk-neutral utility curves, also described in Keeney, were used in the assessment of value for each of the characteristics of the hierarchy. Figure 4 shows an example of the utility values for signal detection range. The assignment of utility values and the performance, physical, and environmental element utility curves were based upon user requirements.

The objective hierarchy was continually updated throughout the FMD systems engineering process as candidate technologies matured and were tested. It served as the primary decision-making tool for initial candidate selection, as well as the subsequent testing and evaluation to designate candidates for transition to full development.

DEVELOP VALIDATION/VERIFICATION CRITERIA

The next step involved developing the criteria necessary to verify the potential solutions against the derived requirements, and further validating them against the user need or mission requirement. The problem statement, operational concept, and requirements set served as the sources for these criteria.

The basic approach involved breaking the problem down into critical operational issues (COI). Measures of effectiveness (MOE) were then developed for each COI to help evaluate whether or not a particular candidate was able to resolve the issue. MOEs were then broken down into specific measures of performance (MOP) that could be measured to verify the candidate design (Roedler & Jones, 2005; Sproles, 2000; Sproles, 2001). Great care was taken to state these criteria in solution-independent terms such that the evaluation did not suggest or favor a particular type of solution.

CANDIDATE IDENTIFICATION AND DEVELOPMENT

The process of identifying candidate technologies began with a meeting of the stakeholders to present the critical need and the resulting operational problem. The technology experts were then given the operational concept and the requirements for the FMD, and asked to identify novel technology candidates to solve the operational problem. An initial set of 15 candidate technologies resulted.

This initial set of candidates was evaluated for feasibility using the objectives hierarchy. This initial evaluation helped to eliminate non-viable candidates. Based upon this evaluation, the initial set of 15 was pared down to 10 promising candidates. Over approximately 3 months, the technology experts worked in parallel to further research and develop their respective ideas for solving the problem.

LAB PROTOTYPE TESTING

Many of the decisions to this point had been made based upon predictions, analytical calculations, and bench tests—analyzing only portions of the device without testing full functionality. It was, therefore, necessary to verify the prototypes through lab testing—testing the full functionality of the device without subjecting it to a realistic operational environment. Since the prototypes were completed at different times, lab testing occurred throughout the development period rather than during a specific test period.

To proceed to the field demonstration, prototypes were required to have been successfully verified against the requirements via the lab testing. The results of the lab tests were fed back into the objectives hierarchy, and the candidate technologies were again evaluated against the objectives. As a result of the verification process, eight prototypes were selected to proceed to field demonstration.

OPERATIONAL PROTOTYPE FIELD DEMONSTRATION

To properly scope the demonstration, the team developed and coordinated a test plan, which outlined the roles and responsibilities of each participant

and the major test objectives. Test and Evaluation Management guidance is well documented (DAU, 2005). The test objectives were derived from the user requirements and MOPs discussed previously. In addition, aircraft flight profile descriptions were developed, and a prioritized test point matrix was created. Finally, data requirements were documented to enable post-flight analysis of prototype performance.

The candidate prototypes were taken to the Nellis Air Force Base test range for the field demonstration. The evaluations were conducted by Air Force operational test agencies representing both user communities: the JTAC ground controllers and the combat aircrews.

Evaluation of Results

The team collected and reviewed the recorded data from the aircraft to determine the maximum detection for each device as well as to evaluate the quality of the detection display as seen from the aircraft. JTAC usability

OVERALL, THE FMD PROJECT SUCCESSFULLY APPLIED SYSTEMS ENGINEERING TO TAKE A CRITICAL USER NEED AND RAPIDLY PRODUCE VIABLE PROTOTYPES THAT COULD BE TRANSITIONED TO PRODUCTION.

assessments and aircrew comments were also gathered and reviewed in order to evaluate the performance of the prototype devices. While not a quantitative measure, the user assessments of the prototypes at this early stage were deemed critical as they would provide the direction for the next phase of development—producing the FMD. That is, once the basic technology is proven, it must still be designed to meet users' expectations for form, fit, and function. With this in mind, a review was conducted on the user assessments of each device, noting favorable characteristics as well as highlighting key areas of concern to be addressed in the next iterations of the development process.

PRIORITIZATION AND SELECTION OF OPTIONS

The results of the field demonstration were fed back into the objective hierarchy. Coupling the updated ranking from the objective hierarchy analysis with engineering judgment and qualitative user feedback, the team selected one candidate technology that met all of the objectives and held the greatest promise of being developed into a system capable of meeting the needs of the user.

Overall, the FMD project successfully applied systems engineering to take a critical user need and rapidly produce viable prototypes that could

be transitioned to production. During the course of the efforts, the systems engineers gained valuable insight into the application of systems engineering to rapid prototyping. The remainder of the article focuses on key observations.

Key Observations and Results

In this section, key observations are made about the FMD project. In particular, each section presents a lesson learned and briefly describes the impact the finding had on the project.

UNDERSTANDING KEY CONSTRAINTS

Observation: Explicitly stating and understanding key constraints helped guide team decision making and brought clarity to choices.

Several key constraints were established at the beginning of the project. By stating the constraints explicitly from the outset, the entire team was focused on the same goals. This shared understanding guided decision making throughout the project. In particular, it made the choice between alternatives relatively clear when conducting trade-offs and candidate evaluations.

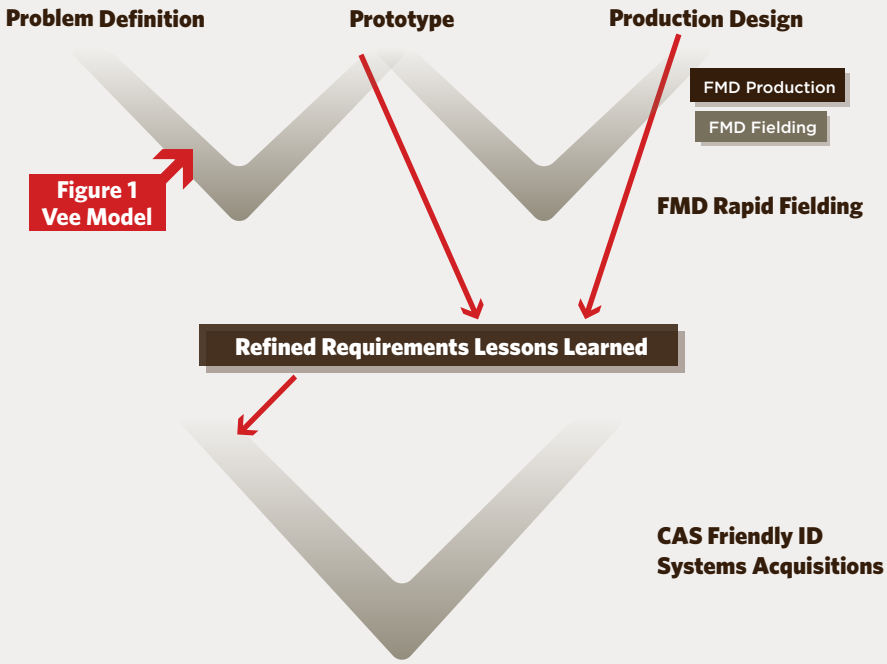
UNDERSTANDING THE LARGER CONTEXT

Observation: An understanding of the larger context helped in developing a tailored systems engineering model and provided a long-term framework for the project.

Part of tailoring the systems engineering approach involved understanding the bigger context in which this specific rapid prototyping effort fit. The programmatic boundary helped communicate scope to all the stakeholders, and helped in day-to-day systems engineering management. Figure 5 places the modified Vee model of Figure 1 into the larger context of a longer-term development fielding of future CAS systems acquisitions. In this context, the rapid prototyping Vee model represents the first increment of the FMD rapid fielding effort. This can also be viewed as the first spiral in the context of the systems engineering spiral model as shown in Figure 6. This understanding helped to modify the classic Vee model to one in which the end state was a demonstrated and validated FMD prototype. This prototype then provided both the input to the next spiral—FMD production design—as well as a refined and validated set of user requirements that can serve as important inputs for future CAS systems acquisitions.

In the spiral development context (Boehm & Hansen, 2001), FMD production design continues the spiral, resulting in a production-ready design to "fill the gap" in capability. After user evaluation and acceptance of the production design, the FMD production and fielding spiral ensues. A formal systems acquisition program for an advanced FMD was envisioned as the next spiral.

FIGURE 5. FRIENDLY MARKING DEVICE (FMD) ACQUISITION CONTEXT



BORROWING FROM OTHER DISCIPLINES

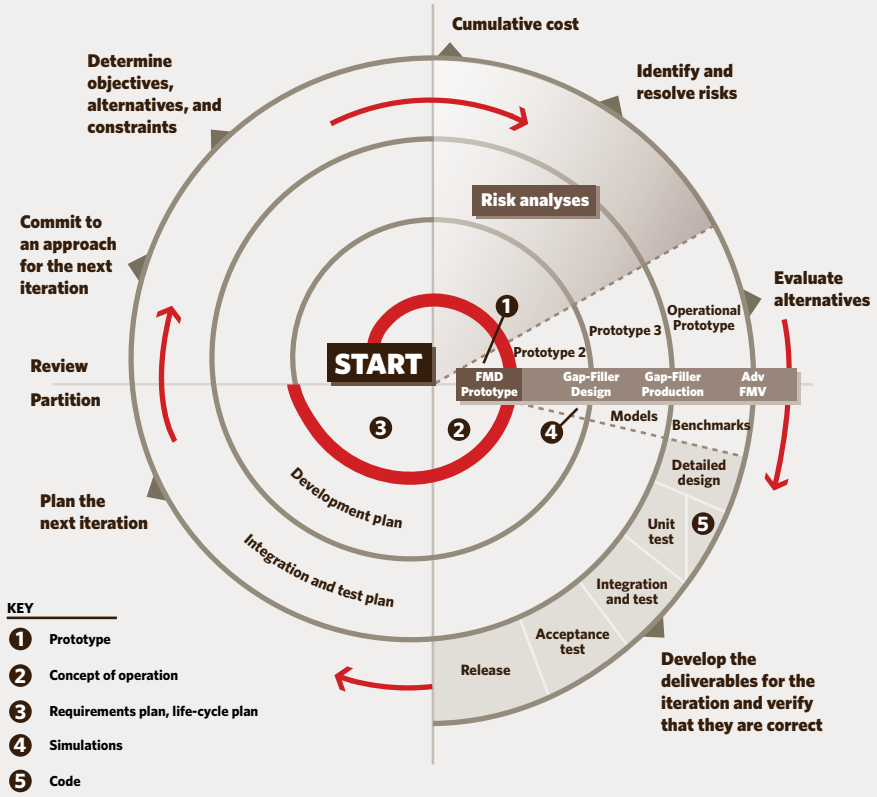
Observation: Proven techniques from software engineering were applicable in a rapid hardware prototyping effort.

The field of software engineering has, through many years of evolution, developed a very elegant approach to tame the complexity and constant change of modern software development. Whereas the waterfall approach (Royce, 1970) treated the requirements definition, design, and testing as distinct, sequential steps, modern approaches such as the Rational Unified Process (RUP) (Krutchen, 2000) emphasize evolutionary development in iterations. The FMD project applied key tenets from the RUP to the rapid development of hardware prototypes.

The sequential waterfall approach presumes that the requirements for the system can be known with a high degree of certainty from the outset and that those requirements remain relatively static during the development process. In a rapid prototyping effort, this is not very likely to be the case, particularly when the user may not know what is within the realm of the possible given the current state of the technology and the key constraining factors.

The RUP, in contrast, makes no such presumption and relies on short development steps with rapid feedback to adapt the design as requirements are clarified. The FMD project resembled the RUP in that it included an

FIGURE 6. FRIENDLY MARKING DEVICE (FMD) IN SPIRAL CONTEXT



initial exploratory phase much like an inception iteration. This phase lasted approximately 4 weeks. It included the initial meetings with the user and the entire project team. Accomplishments included creating the operational concept (vision), collecting the user's initial requirements, and defining the scope of the project. In addition, the initial technology exploration was used to check the feasibility of the novel technology ideas. Based upon initial design ideas and performance estimations, the user was able to refine the requirements and help eliminate some technology candidates because of their size, weight, or power consumption. The result was the initial list of ten candidates.

The rest of the project (as of this writing) was much like the elaboration phase of the RUP. The ten initial candidates were built into functioning prototypes. As the designers completed various phases of their fabrication work, more was learned about each of the candidates. This new knowledge was rapidly fed back into the process to further refine requirements and guide the project.

Timeboxing was also effective for the FMD project. Two candidate technologies were not mature enough to proceed to the field demonstration. Rather than slip the date, those candidates were excluded from the field demonstration with the intent to continue their development and take them to

the field during a later iteration. In the interim, feedback from poor field results for candidates with similar technology (i.e., employing a similar type of emitter) showed that one of the immature candidates would not be a viable solution. That candidate was eliminated, saving both time and money.

SELECTING AND USING TOOLS

Observation: Selection of tools suited to the tailored systems engineering approach facilitated the decision-making process.

In making any decision, the development of a value model enables the systematic identification and application of user value to multiple attributes of a decision. The FMD rapid development environment required a decision tool that effectively used the limited candidate attribute information, preserved design-independent solutions, did not impose a large analytical overhead, and effectively identified the most viable alternatives.

Within the framework of the objectives hierarchy, a "living" multi-attribute decision tool was created by revisiting the phases as new and refined information was obtained. In this way, any new information, such as better performance estimates or actual test results, was quickly fed back into the objectives hierarchy to give a new snapshot of the solution space in terms of the stakeholders' objectives.

Buede (2000) discusses how the use of objectives hierarchy can be used throughout the systems design life cycle to support trade studies. Another somewhat unique application of the tool was that the objectives hierarchy was used not only throughout the design process (down the left side of the Vee model), but also as an analysis tool during the prototype evaluation process (up the right side of the Vee model) as well. The objectives hierarchy provided a mechanism to integrate actual prototype test data with long-term rapid production unit attributes such as projected weight, dimensions, etc., into a single, scoreable measure to compare alternatives. Doing so ensured that important production and usability issues were considered (via estimates and predictions) in the final candidate selection.

DEVELOPING IN PARALLEL

Observation: Parallel development helped reduce the overall risk of the project.

Managing risk is part of any project. Rapid prototyping is, arguably, itself a form of risk management in that the aim is to explore a solution space. However, in the case of the FMD project, the rapid prototyping attempted to respond to a critical operational need. In this light, there was significant incentive to ensure that some solution was identified that would be acceptable to the user.

From the outset of the project, the team sought to reduce the risk that no acceptable solution would be found. A classic risk mitigation technique when dealing with innovative and often immature technology is to pursue multiple

parallel paths towards the same goal. This approach was used on the FMD project. At the initial evaluation, rather than selecting a single candidate to build and test, the team attempted to prototype all of the candidates that were predicted to meet the user need based upon the estimates and performance calculations supplied for the first iteration of the objectives hierarchy.

Another way that the parallelism helped the effort was that lessons learned by one of the parallel tracks could be fed back into the rest of the tracks to help guide and refine the remaining work. For example, early lab tests showed that modulation was especially helpful in making a signal more discernible to the observer. This information was then incorporated into the remaining designs to help further reduce risk.

MAINTAINING RIGOR IN A RAPID REACTION PROJECT

Observation: A development effort can be responsive to critical operational needs while maintaining the rigor of systems engineering.

Organizations often have very formalized and standardized systems engineering processes for product development. Within the DoD, the systems engineering process is often associated with a series of documentation requirements (formal plans, requirements, etc.) flowing through a rather large management and oversight function, coupled with a very directive series of formal reviews (DAU, 2001; Department of Defense, 1993). However, the underlying principles of systems engineering are present in the DoD process (DeFoe, 1993). When the overhead of the standard formal review and documentation requirements is reduced, a very realistic approach to conducting rapid and innovative development is generated. In fact, a common misperception is that the DoD imposes a specific systems engineering process. Rather, the *Defense Acquisition Guidebook* outlines standard industry systems engineering models and emphasizes that "models usually contain guidance for tailoring, which is best done in conjunction with a risk assessment on the program that leads the program manager to determine which specific processes and activities are vital to the program" (DAU, 2009, p. 12).

Based upon the results of the FMD project, the conclusion is drawn that by effectively tailoring the application of classic systems engineering methodologies to the problem at hand, a development effort can be responsive to critical operational needs while maintaining the rigor of systems engineering.

HEURISTICS DISCUSSION

Rather than attempting to provide a recipe for tailoring the application of systems engineering to a rapid prototyping effort, this section presents the lessons learned during the FMD project in the form of heuristics that can help guide similar efforts in the future (Maier & Rechtin, 2002).

A CUSTOM APPLICATION

Heuristic: Tailor the application of classic systems engineering practices to the specific problem at hand.

There is not a single, approved way to apply systems engineering to a given type of project. Each critical user need or problem is unique. While similarities may exist across any set of problems, each exists in a slightly different context and has its own set of challenges. Therefore, it is incumbent upon the systems engineers to examine these discriminating factors and apply systems engineering accordingly to arrive at a suitable approach. In particular, the systems engineer: must understand the larger context within which the current project resides; should look for similarities in and borrow from other projects and disciplines; and should select the appropriate tools for the job.

KEEPING THE FEEDBACK LOOP OPEN AND RAPID PROVED KEY TO THE DECISION PROCESS.

Despite the fact that each project is unique, lessons learned on similar projects and in other disciplines may prove useful. The FMD project looked to the software engineering discipline for lessons learned and for techniques to employ in developing prototypes where time is short and requirements are not fully known or understood. Keeping the feedback loop open and rapid proved key to the decision process.

Having the right tool for the job often makes a world of difference in the effectiveness of the effort. The FMD project needed a decision tool that could take the rapid feedback and continually provide an up-to-date snapshot of the solution space. The objectives hierarchy was well suited to this task. As test results came in and were entered into the tool, a new snapshot of the solution space allowed the team to continue to pursue promising technologies and drop the ones that did not perform well.

THE TEAM INTEGRATOR

Heuristic: Systems engineers can integrate the team by being the hub of a collaborative process.

When a need is critical and time does not permit the formation of a formal team, groups may come together in an ad hoc fashion to respond. The systems engineers can help to integrate the team's efforts by creating a collaborative process and serving as the hub. This role may include responsibilities such as creating or setting up collaboration tools and serving as the repository for information. In short, the systems engineer must treat the team much like a system of systems that can be integrated into a cohesive whole.

A USEFUL RESULT

Heuristic: Manage risk aggressively, but if no solution emerges, ensure that something beneficial comes from the effort—failure is not an option.

Clearly a team would prefer to see a viable solution emerge from the rapid prototyping process. Managing the risks in the process is critical, just as it is in nearly any endeavor. However, the effort should not be considered a failure if a solution does not emerge. In exploring the solution space, considerable knowledge has been gained and requirements are better understood. All of this knowledge can be fed into future efforts, allowing them to benefit from that which has gone before. Therefore, the systems engineers must aggressively manage the risks to increase the probability that a solution will be found, but must also extract the key lessons and knowledge and feed them into future efforts.

MANAGING RISK REQUIRES KNOWING THE "BOX" IN WHICH THE PROJECT MUST OPERATE.

Managing risk requires knowing the "box" in which the project must operate. That is, the team must understand the key constraints. In so constraining the effort, the team must determine what must be given up to remain within the box. On the FMD project, not modifying aircraft eliminated a significant portion of the solution space—the price for meeting the schedule and budget. Understanding this box helped frame each decision.

Conclusions

At the beginning of the article, the question was posed: Can a development effort be responsive enough to react to critical needs while still benefiting from the rigor of systems engineering? Experience from the FMD project has shown that an effort can indeed maintain the rigor of systems engineering, yet still be nimble enough to react to critical user needs in a dynamic environment. While the approach taken for the present effort will certainly not work for every rapid prototyping effort, the key observations provide some overarching lessons to guide future efforts. The heuristics provided are intended to be a few more tools in the systems engineering toolbox to aid the practitioner in applying systems engineering to meet emerging critical operational needs in a rapid prototyping effort.

ACKNOWLEDGMENT

The authors are grateful for the hard work and dedication of Systems Engineering students and Air Force officers: G. Buckner, G. Buttram, M. Cannon, A. Collazo, and M. Jiru. The authors also thank Dr. Alok Das from the Air Force Research Laboratory (AFRL) for sponsoring this project, and Robert Pearson, AFRL focal point, for their invaluable support.

Author Biographies

Dr. John M. Colombi is an assistant professor of Systems Engineering at the Air Force Institute of Technology. He teaches graduate courses and leads sponsored research in support of the Systems Engineering program. Before joining the faculty, Colombi led Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance systems integration activities, including systems engineering for the Airborne Warning and Control System at Hanscom Air Force Base. Colombi has served at the National Security Agency developing information security and managed communications networking research at the Air Force Research Laboratory.

(E-mail address: john.colombi@afit.edu)

Dr. Richard G. Cobb is an assistant professor of Aerospace Engineering at the Air Force Institute of Technology. He chairs the graduate Space Systems program, teaches graduate courses, and leads sponsored research projects within the department of Aeronautics and Astronautics. Before joining the faculty, Cobb led the reliability-centered maintenance program for the U.S. Air Force's gas turbine engine fleet. He has also managed several recent Department of Defense-sponsored space flight experiments.

(E-mail address: richard.cobb@afit.edu)

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CAN APPLYING ORGANIC AND INDUSTRY BEST PRACTICES IMPROVE FOREIGN MILITARY SALES SUPPORTABILITY?

Brian B. Yoo, Duane W. Mallicoat, and Timothy "Tim" K. Simpson

This article provides a brief overview of *Foreign Military Sales (FMS)*, its role in the ever changing dynamic environment that we live in, and finally how some of the specific FMS processes can be improved through the application of logistics best practices and initiatives. The ultimate goal is to continually improve the processes associated with FMS to create a win-win scenario for the Department of Defense and affected stakeholders. The best practices within the framework of the ten *integrated logistics support (ILS)* elements discussed within this article should be merged into the current acquisition or logistics support strategy.

Keywords: *Foreign Military Sales (FMS), Defense Reform Initiative (DRI), Defense Security Cooperation Agency (DSCA), Defense Institute of Security Assistance Management (DISAM), Integrated Logistics Support (ILS), NATO, South Korea, Japan, Taiwan, China, Cooperative Logistics Supply Support Agreement (CLSSA), Defense Reutilization and Marketing Service (DRMS), Defense Transportation Network (DTN)*

image designed by Harambee Dennis »

Foreign Military Sales
SALE

Most civilian and military Department of Defense (DoD) employees have heard the term "FMS" sometime during their career. At first glance, the concept of Foreign Military Sales (FMS) appears simple and straightforward—sell military hardware, software, services, or training to a friendly nation. FMS can be a valuable tool to supplement military cooperation efforts and improve security cooperation with friendly nations. But most notably, FMS is most often seen merely as the way we sell military material to other countries. This perception, however, is misleading—there is a lot more to FMS than meets the eye. It is a complicated process managed by numerous agencies, laws, and regulations. FMS falls under the umbrella of United States Security Assistance, authorized by the Foreign Assistance Act (FAA) of 1961, and the Arms Export Control Act (AECA) of 1976. The receiving country provides reimbursement for defense material and services transferred from the United States.

FMS Management History

The FMS program is that part of Security Assistance authorized by the AECA and conducted using formal contracts or agreements between the U.S. Government and an authorized foreign purchaser (DoD, 2003). The *Defense Reform Initiative (DRI)* of 1997 first coined the term Security Cooperation. Since the introduction of DRI, the overarching management responsibilities for many of the DoD-authorized international programs have for the most part been centralized and transferred to the *Defense Security Cooperation Agency (DSCA)*. The DSCA was formerly known as Defense Security Assistance Agency (DSAA), which primarily was responsible for many of the Department of State's Security Assistance programs authorized by the FAA and the AECA (DISAM, 2007). The DRI centralized various aspects of foreign Security Assistance and delineated key responsibilities between the State Department and the DoD. The activity of selling weapon systems to friendly foreign governments becomes a leveraging tool of U.S. foreign policy and provides the United States with an avenue to conduct joint operations with the receiving nation (House, 2000). Executive Order 11958 (1977) allocates authority and responsibility for Security Assistance principally to the Secretary of Defense and the Secretary of State. The Secretary of Defense authority is further delegated to the Under Secretary of Defense for Policy and to the Director, DSCA, in DoD Directive 5105.65 (DoD, 2000). The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) supports and consults only with DSCA, and USD(AT&L) ensures its strategic goals complement the two organizations' Security Assistance objectives. Bottom line: FMS is a crucial tool in promoting U.S. foreign policy and national security interests.

During the cold war, U.S. Security Assistance programs revolved around the need to contain the Soviet Union. To this end, American Security Assistance programs provided military training and other support to countries that U.S. policy makers viewed as essential to success in the fight against Communism.

This Security Assistance approach changed after the fall of the Berlin Wall in 1989. The end of the cold war brought with it a phased downsizing of the U.S. military starting in the early 1990s. As a result, the numbers of FMS agreements have steadily increased in the last decade. The total FMS annual funding increased from $8 billion in 1997 to $21 billion in 2006 (DSCA, 2006, pp. 1-17). As we can see from this statistic, the growth of FMS would also create a growth in the potential impact of best practices and initiatives—specifically, as noted in this article, to the logistics support elements.

FIGURE 1. FOREIGN MILITARY SALES AGREEMENTS INCLUDES CONSTRUCTION (DOLLARS IN BILLIONS)

Note: Information provided from the **Historical Facts Handbook** *(Defense Security Cooperation Agency, 2006)*

Figure 1 provides not only an interesting trend in FMS growth, but an increased opportunity to realize savings and efficiencies "if" organic and industry best practices are applied. Although we only address three of the ten logistical elements, the opportunities and impacts discussed in these three elements indicate the potential for additional savings when applicable best practices are applied over the remaining seven elements.

As seen in Figure 1, and based on research conducted by the authors, it was found that the enhancement of logistics has significantly enhanced the effectiveness of the DoD operations, as well as those FMS cases that have chosen to incorporate the enhanced method. Where are the results you may ask? Figure 1 also reflects real savings to be gained by using economies of scale for order quantities, incorporating either organic or industry capabilities for maintenance,

and using Federal Express, United Parcel Service, or DHL International as a source for parts delivery. As the Naval Aviation Logistics Process Improvement Team (LPIT) found out during an effort to improve supportability of newly procured weapon systems in the domestic and international markets—both commercial and military—the prime aircraft manufacturer began offering hybrid support concepts, which some call Enhanced Contractor Initial Support (ECIS), for supporting the introduction of new systems. Per Bernard (2003), the ECIS combined both the aspects of what would be considered a traditional U.S. Government support concept with the Original Equipment Manufacturer (OEM) maintenance, supply support, in-service engineering support, and training options. If we are able to successfully create an environment of support for the FMS customer, this could create a cyclical process where the FMS customer returns to request either an increase of systems or other available systems. In this case, improved logistics support could improve FMS supportability but also result in new or follow-on FMS agreements.

Due to the continued and expanded role of FMS, the Defense Acquisition University entered into an agreement with the Taiwanese Ministry of National Defense to provide several courses related to life cycle logistics during 2009, and possibly beyond. This type of agreement to provide and receive training will only improve support to our allies and provide economies of scale to our defense industry, making it more efficient. Also, through this type of partnership, the Taiwanese government became aware of the DoD's effort to incorporate Performance-Based Logistics (PBL) as a preferred support strategy, and they are also looking to incorporate it into their weapon systems (J. Cain, personal communication, May 28, 2009).

Potential FMS Benefits

There can be substantial benefits in using FMS as part of security cooperation applicable to DoD and the partnering country. An example of the potential benefits came to light when the former administration announced the latest potential U.S. Middle East FMS opportunity. The administration offered more than $60 billion in new weapons and military assistance to Egypt, Israel, Saudi Arabia, and other U.S. allies in the Middle East (Houska, 2007). These potential agreements can offer potential benefits in a variety of areas including strategic partnerships, mutual good will, as well as a boost to the U.S. industrial and economic base.

Some of the tools that might be used to support a potential FMS agreement include: subject matter expert exchanges, conferences, large multinational exercises, where all of these fall under the larger umbrella of "Security Assistance" and "International Cooperation" (Van Horn, 2007). As we have now shown, FMS is not simply selling hardware to a friendly nation.

The Need to Improve FMS

Improving cooperation with friendly nations can be brought about in numerous ways. One way would be to provide a more effective and supportable FMS program. As previously discussed, the general approach of any FMS program should be to: 1) provide a faster and more efficient output performance that meets or exceeds the requirements set forth by the international customer; 2) take advantage of potential initiatives and existing best business practices; and 3) improve life cycle support. One approach might be to incorporate the FMS case into an existing or new PBL agreement. According to Weinberger (2007), the U.S. military can recount successes where a PBL is established to support the international customer's platform using a metric that produces an outcome of most benefit to the customer. Several international PBLs exist today; two worth mentioning are the F/A-18E/F Integrated Readiness Support Teaming (FIRST) contract that holds a single OEM integrator responsible for the reliability and availability of numerous systems; and an In-Service Support Contract (ISSC) with Boeing, which brings together common air vehicle sustainment support efforts for the Navy and seven FMS international customers.

The DSCA has been working to transform FMS since the turn of the millennium. The agency started off in 2000 with ten initiatives under the leadership of Lt Gen Tome H. Walters, Jr., USAF, [then] director of DSCA. The initiatives included the Civilian Workforce Initiatives, Standby Letter of Credit in Lieu of Termination Liability Prepayments, Improved Payment Schedule Methodology, and Team International. The main objective of the initiatives was to improve the FMS process for both the international customers and U.S. defense industry alike. While some of these initiatives have been implemented and others are ongoing, there is always room for continuous improvement. These improvements will leverage advanced informational technologies and enhance the professionalism of the FMS workforce (Beauchamp, 2002). Informational technologies are the backbone of the DoD logistics systems, which aid in the management of programs and help calculate requirements through use of various database systems.

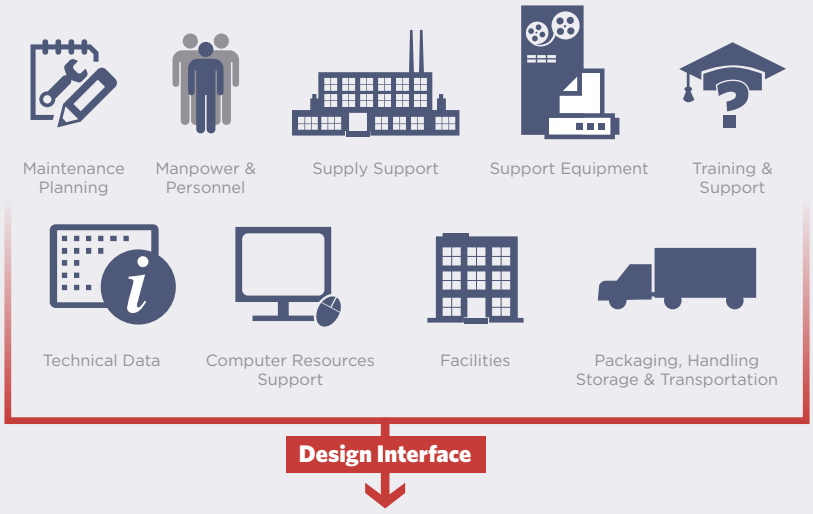
The need to improve FMS was also evident from the Navy's perspective. Naval Air Systems Command has a Naval Aviation FMS LPIT to integrate and streamline the processes that logistically support Naval Aviation FMS programs. The LPIT consists of the FMS Logistics Steering Committee, the International Logistics Enterprise Team, the FMS Customer Advisory Group and Industry Advisory Group, and the Logistics Support Office. The various groups work together at conferences and in separate meetings to create and enhance the Navy's FMS support (Bernard, 2003). This is a classic example of supporting the user through improved logistics support.

Improving FMS Through Logistics

As revealed in the previous paragraphs, initiatives at the macro level are available to improve FMS. Also, mentioned earlier was the fact that Security Assistance and FMS constitute a complex beast, touching legal statutes, funding constraints, and competing agendas from different stakeholders, similar to the three DoD decision support system processes of the Joint Capabilities Integration and Development System (JCIDS); Defense Acquisition System; and the Planning, Programming, Budgeting, and Execution (PPBE) process, which make up defense acquisition.

Per DoD 5105.38-M (2000), the Department of Defense shall take reasonable steps to support systems that have been phased out of DoD inventory and acquired by foreign nations, including items that were never adopted by U.S. Forces. Something that can be addressed in a relatively tangible way is improving the logistics support to foreign countries, and creating a climate of mutual support and cooperation among the U.S. Government, the U.S. defense industry, and the FMS countries. Logistics can also be construed as a complex process, depending on how it is defined. For purposes of this article, we use the Defense Acquisition University's ten Integrated Logistics Systems (ILS) elements (Figure 2), consisting of maintenance planning; manpower and personnel; supply support; support equipment; training and support; technical data; computer resources support; facilities; packaging, handling, storage, and transportation; and design interface. The highlighted Integrated Logistics Support (ILS) elements (Figure 2) will be discussed to show that advancements

FIGURE 2. INTEGRATED LOGISTICS SUPPORT MODEL



Note: From the Defense Acquisition University, Fort Belvoir, VA (2000). Intermediate Acquisition Logistics course material.

in defense supply support; maintenance planning; and packaging, handling, storage, and transportation processes can improve FMS.

As noted by senior leadership at the Office of the Secretary of Defense level, post-production costs of operations and maintenance make up approximately 60–70 percent of the life cycle costs of a major system.

SUPPLY SUPPORT

As former military logisticians, we would be remiss if we did not start by mentioning the ever-present supply and parts shortages, which fall under the ILS element of supply support. The list of reasons why parts are not available is endless. In every Supply Chain section of the Defense Acquisition University's LOG 236 (Performance Based Logistics) class (DAU, 2009), whenever a question is asked of the students as to why a system is not available due to parts, no shortage of explanations is forthcoming. The litany of explanations includes poor forecasting, low inventory level, inaccurate demand history, funding shortfalls, long lead items, unforeseen surge or failures, sudden increase in demand, high cost, obsolescence, diminishing manufacturing source, and material shortages.

Forecasting affects all aspects of logistics, whether it be spares requirements, warfighter needs, projected funding, flying hours, technology improvement, rate at which experienced workers will retire, or even the types of conflicts that war planners project—all are at best mostly educated guesses. While we have gotten better at forecasting and developing models to improve forecasts, forecasting is still an inexact science. Factors such as poor communication due to a language barrier or cultural differences, even with the friendliest of allies, can magnify the forecasting error exponentially.

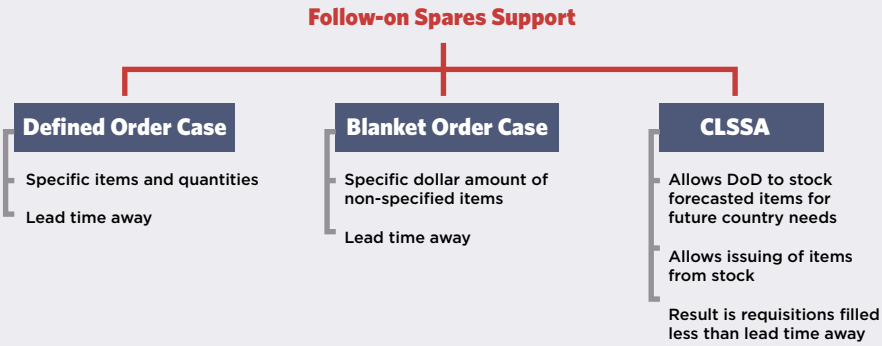
One of the lesser known options to improve logistics support for FMS is use of the *Defense Reutilization and Marketing Service (DRMS)*. With the advent of the Internet, finding spare parts has become lightning fast, and many Web sites are available. However, the main advantage of DRMS is that it receives over $18 billion worth of excess property each year from all armed services, which is then *sold in an "as-is" condition at 5–50 percent of original value.* FMS is one of the programs qualified to receive DRMS property, subject to the rules and regulations of the AECA and the FAA, and all cases are congressionally notified (Schillinger, 1999).

So we have discussed the F-18 FIRST program, the success of that particular program, and identified the flexibility, efficiencies, and economies of scale that PBL brings to a program; however, program success and a successful logistics strategy are not a be-all/end-all panacea. Since the Department of Defense sets the requirement to define the supply support strategies, prudence dictates that the Program Management Office investigate any and all organic industry and non-DoD industry solutions. Other issues have surfaced that will need to be addressed with international customers, specifically the repair and return of their equipment. Cases have been reported wherein FMS customers turned in a specific serialized item, expecting that the same exact repaired item would be

returned. This strategy can not be supported when the PBL metric requires a quick replacement of the component.

Other successful cases include the F/A-18 "FMS Spares Call" that brings together individual country procurements to receive the financial benefit of larger "economies of scale" procurements; and the AIM-9X combined procurement that saved the U.S. DoD over $3 million in cost avoidance. The United Kingdom Ministry of Defence (MoD), through a partnership with Raytheon, uses the best business practices of single integrator to support their F/A-18 aircraft by employing a strategy whereby incentive mechanisms drive supplier performance and cost reductions.

FIGURE 3. THREE TYPES OF FMS SPARES SUPPORT MODELS (AIR FORCE SECURITY ASSISTANCE CENTER, 2006)

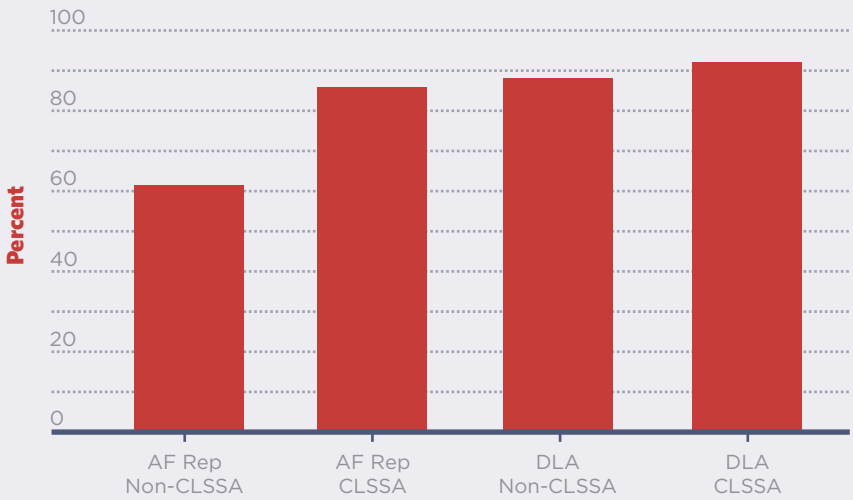


The basis of any U.S. Government-sponsored sale of defense articles or services is the letter of offer and acceptance (LOA), an agreement between the two governments (seller and the purchaser). The LOA is commonly referred to as an FMS case. As a point of reference, three types of spares support are available to FMS countries (Figure 3). First is the Defined Order case, which is most commonly used for sale of major end items that require security controls throughout the sales process. This is commonly referred to as a standard sales or firm order by the U.S. Army and U.S. Air Force, respectively. Another option is the Blanket Order case, which is an agreement between a customer and the U.S. Government to purchase a specific category of items or services at a set dollar amount with no definitive listing of the exact items or quantities desired. Customers may requisition against a Blanket Order case as long as the case has funds available. The final and best method of obtaining spares support from the United States is the use of the *Cooperative Logistics Supply Support Agreement (CLSSA)*. This arrangement is designed to provide responsive follow-on spare part support for U.S. military hardware owned by foreign countries.

The main advantage of CLSSA for a customer is that it allows support for the purchaser on an equal basis with U.S. units having the same force activity designator (FAD), which relates to the mission of the activity and the urgency or

need. The caveat to this statement is that even our allies usually receive a lower FAD. But even with a lower FAD, using the CLSSA spares support approach far outweighs the other two support types. If the Defined Order case approach is taken, then the FMS customer might pay a higher price instead of enjoying cost avoidance due to economies of scale, and may expect an extended awaiting parts (AWP) time. The Blanket Order case approach finds the FMS customer having to provide a substantial amount of cash to cover the cost of components not yet needed. There may be some FMS customers that do not have the ability to front large quantities of money to cover unknowns, or perhaps this approach may be resisted for cultural reasons. The Blanket Order case approach also leaves the FMS customer with an extended AWP time. So the bottom line benefit to the CLSSA approach is that the FMS customer receives support on an equal basis with U.S. units having the same FAD; thus, it shortens requisition fill times (Figure 4) for items that come from DoD stock (DISAM, 2007).

FIGURE 4. REQUISITION FILL TIMES LESS THAN 180 DAYS



Source: Air Force Security Assistance Center, 555th ILS/Supply Flight, CLSSA Performance Brief, August, 2007.

The logistical element of supply support, which in this instance includes the art of forecasting and spares support approach taken, has been shown to be a best practice that, if managed properly, can be a significant readiness and maintainability enabler for the FMS country. With the training that is inherently tied to most of the ILS elements, education and better communication with FMS customers will serve the best interests of DoD, its allies, and affected stakeholders. The obvious benefit of the FMS customer using CLSSA is the consolidated larger purchase, resulting in lower per unit cost for the customer.

MAINTENANCE PLANNING

As acquisition and logistics practitioners, we all understand that when designing an aircraft, all the maintenance planning aspects are considered up front and early regarding what the maintenance requirements will be to support the system. However, when a legacy system is sold to an FMS customer, how does this apply *after* the production effort is complete? So let's take a moment to look at several examples where maintenance planning efficiencies were improved.

Maintenance planning was used to improve FMS logistics support in Naval Air Systems Command's In-Service Support (ISS). The F/A-18 community wanted to ensure that post-production logistics and engineering support would be available for out-of-production F/A-18 FMS customers. ISS was established as a means to keep the fleet modern and operationally viable, while continuing to develop ways to reduce maintenance costs and overcome the normal obsolescence of components and systems. The ISS program has become the standard method that enables the F/A-18 FMS communities to provide FMS customers with access to the U.S. Navy and the prime contractor for long-term support to the F/A-18 weapon system (Chamberlain, 2000). In this case, it needs to be part of the FMS case to capitalize on the efficiencies that can be captured by this approach.

The AV-8B Harrier is another area that capitalizes on commonality. Both the U.S. Marine Corps and the Italian Navy operate the AV-8B using the same maintenance practices and concepts. The approach of having the same manuals, inspection intervals, and maintainer qualifications enables the FMS customer to deviate from an individual maintenance concept that could increase support costs. The Navy C-40 Clipper, a modified Boeing 737 platform, is another example where best commercial practices used by commercial airlines were adopted by the Navy. This means that C-40 Clippers and their crews can travel worldwide, confident that the aircraft can be serviced and maintained.

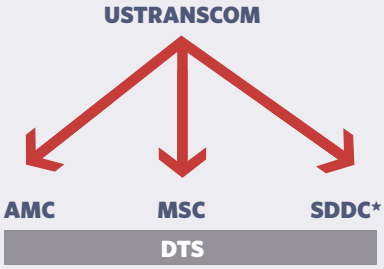
What we've shown under maintenance planning is that despite the fact that a platform was not designed with potential FMS applications does not mean that efficiencies cannot be gained by using a variety of organic government, industry, or Federal Aviation Administration best practices. Thus, in the area of maintenance planning, providing the FMS customer with long-term support from the OEM (possibly via the use of a Sustaining Engineering Contract) could produce the framework to build a long-term sustainment support program. Key to a successful FMS support program is avoiding the loss of system assets due to a deficiency of maintenance repair technical support. Again, we can see the potential for improvements applicable to the FMS arena.

PACKAGING, HANDLING, STORAGE, AND TRANSPORTATION

When talking about transportation, we first must understand what is available from the air and sea under the Defense Transportation System (DTS).

The U.S. Transportation Command (USTRANSCOM) consists of three elements. The *Air Mobility Command* transports material and personnel around the world through both organic and commercial contracted air carriers. The *Military Sealift Command* transports material around the world through organic and contracted commercial surface ships. The *Surface Deployment and Distribution Command* operates the military ports in both the United States and overseas. These three elements are referred to as the DTS (Figure 5).

FIGURE 5. USTRANSCOM AND THE DEFENSE TRANSPORTATION SYSTEM



**Surface Deployment and Distribution Command*

USTRANSCOM is responsible for the movement of about 560 tons of freight per day. However, actual FMS shipments comprise only about 6 percent of USTRANSCOM's annual business. For a variety of reasons, in-transit visibility is not consistently available to FMS customers, as noted by the Defense Institute of Security Assistance Management (DISAM, 2007). The DoD prefers not to be involved in the movement of FMS material and encourages customers to be self-sufficient in arranging for transportation and obtaining in-transit visibility data. USTRANSCOM has come up with a solution for better visibility and accountability for FMS material through the Enhanced Freight Tracking System (EFTS). Per DSCA Memorandum (2008), EFTS is a secure Web-based application that provides in-transit visibility of FMS shipments. Resident in the Security Cooperation Information Portal, EFTS serves as a consolidated source for FMS in-transit information. Ultimately, EFTS applications will evolve to provide visibility of the FMS distribution pipeline for all classes of supply and modes of transportation, with tracking visibility of outbound cargo from the United States to the FMS customer's country or cargo returning to the United States or a U.S facility overseas.

Now that we have an understanding of what is available within the defense and transportation sectors, what of the transportation experts that support the global economy? Can the advantages that they bring to transportation be harnessed and capitalized on to benefit not only the Department of Defense systems, but also FMS? We need to understand the capabilities that FedEx,

UPS, or DHL might bring to this equation. These commercial delivery services may serve as strong enablers in moving requirements to and from major staging areas. But in actuality, the supporting program office must understand the entire transportation scope in order to apply the commercial/industrial capabilities in an effective manner. Anyone now has the capability to go online, order an item, and have it shipped to their location from practically anywhere in the world, quickly and conveniently. In many cases, tracking visibility is also offered online. Obviously, the potential of increased efficiency of transportation can be gained by applying the best aspects of the DTS and the global transportation carriers.

Conclusions

This article provides a broad overview of FMS and its importance to the U.S. Government, defense industry, and allied nations; and how FMS processes can be improved, specifically through logistics. While only three of the ten ILS elements were addressed—supply support; maintenance planning; and packaging, handling, storage, and transportation—any of the other ILS elements can be leveraged to improve FMS support. This article shows that FMS support can be improved through logistics via advancements in both organic and commercial capabilities. The authors' intent, however, is that it serve as a catalyst for program managers, their allied counterparts, and affected stakeholders to pursue improvement in logistics processes, thereby increasing weapon systems supportability and accelerating support to joint warfighters.

Author Biographies

Mr. Brian B. Yoo is a professor of Life Cycle Logistics, Defense Acquisition University. He spent over 20 years of active duty in a variety of logistics positions throughout the Air Force and Department of Defense. He holds a Bachelor of Science from the U.S. Air Force Academy and a Master of Science in Logistics from the U.S. Air Force Institute of Technology.

(E-mail address: brian.yoo@dau.mil)

Mr. Duane W. Mallicoat is currently the Associate Dean of Outreach and Performance Support at the Defense Acquisition University Mid-Atlantic Region. He teaches Program Management and Logistics courses. He holds a Bachelor of Science degree from New York Regents University and a Master of Administrative Science degree with a major in Management from Embry-Riddle Aeronautical University. Prior to joining DAU, he served over 35 years in the U.S. Navy, where his career experience focused on program management and logistics.

(E-mail address: duane.mallicoat@dau.mil)

Mr. Timothy "Tim" K. Simpson is currently a professor of Acquisition Management at the Defense Acquisition University Mid-Atlantic Region. He teaches Program Management and Logistics courses. Prior to arriving at the Defense Acquisition University, Mr. Simpson was the Propulsion Lead, Assistant Program Manager Logistics, for PMA-274 in-Service and VH-71 Presidential Helicopter Programs located at Naval Air Systems Command. He holds a Bachelor of Science degree in Professional Aeronautics and a Master of Administrative Science degree from Embry-Riddle Aeronautical University.

(E-mail address: tim.simpson@dau.mil)

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A MULTI-CRITERIA DECISION MODEL FOR MIGRATING LEGACY SYSTEM ARCHITECTURES INTO OPEN SYSTEM AND SYSTEM-OF-SYSTEMS ARCHITECTURES

Cyrus Azani

Full-spectrum dominance in battlefield, cost-effective development of capabilities, timely reaction to evolving threats and technologies, and system and process flexibility can be greatly enabled through the application of open systems strategies. Such strategies are effective business and technical approaches for assessing the appropriateness of developing modular and *open architectures* for stand-alone as well as system of systems. This article will introduce an integrated methodology for assessing existing systems and migrating their architectures into modular and open architectures. The proposed method integrates open systems strategies with the *Analytic Hierarchy Process (AHP)* and *Goal Programming (GP)*—two powerful decision-making models—to evaluate the appropriateness of open systems migration, rank migration candidates, allocate resources among them, and develop open architectures for selected systems.

Keywords: *Legacy Migration, Open Architecture, System of Systems Engineering, Analytic Hierarchy Process (AHP), Goal Programming (GP)*

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Modular Open Systems Approach

(MOSA)

Timely reaction to evolving threats and technology requires agile system architectures that could quickly and cost-effectively be integrated and reconfigured within family of systems and joint system of systems warfighting constructs. Affordable agility and reconfiguration will demand open and modular forces, systems, and system of systems (SoS). The recent change in U.S. Army strategy from division-centric structures to modular brigade combat teams; publication of DoD Directive 5000.01 (DoD, 2003), which mandated implementation of the Modular Open Systems Approach (MOSA); the *Naval OA (Open Architecture) Strategy* (2008); and the *Open Technology Development Roadmap Plan* (Department of Air Force, 2006)—all are testimony to a shift in warfighting and acquisition within the DoD. If applied effectively, an open

THIS ARTICLE PROPOSES AN INTEGRATIVE MODE/METHOD FOR MIGRATING LEGACY SYSTEMS INTO OPEN SYSTEMS IN A FAMILY OR SYSTEM OF SYSTEMS CONTEXT.

and modular architecture can enhance the adaptability of defense systems to changes in threats and technology, reduce the total ownership costs of systems, and improve life cycle supportability. Moreover, by following an open system strategy in acquisition of systems, the programs will be in a better position to leverage investments made throughout the defense industrial base to produce new commercial products, practices, and technologies that will integrate warfighting capabilities more easily in a system of systems environment and field superior capabilities more quickly and affordably. Furthermore, an open system strategy considers life cycle support requirements up front, permits system evolution with technology development, opens the diminishing defense industrial base to commercial know-how and products, anticipates technology obsolescence in system design, and supports continuing technology insertion throughout the system life cycle.

The best strategy for developing an open system architecture is to follow the MOSA, originally proposed by Azani and Flowers (2005). This approach is an integrated business and technical strategy that employs a modular design and, where appropriate, defines key interfaces using widely supported and consensus-based standards that are published and maintained by recognized industry standards organizations (i.e., open standards). By following this approach, the programs will first make a business case for open systems and then, through adherence to five major MOSA principles, develop an open architecture for the system under consideration (Azani & Khorramshahgol, 2005).

FIGURE 1. THE MODULAR OPEN SYSTEMS APPROACH

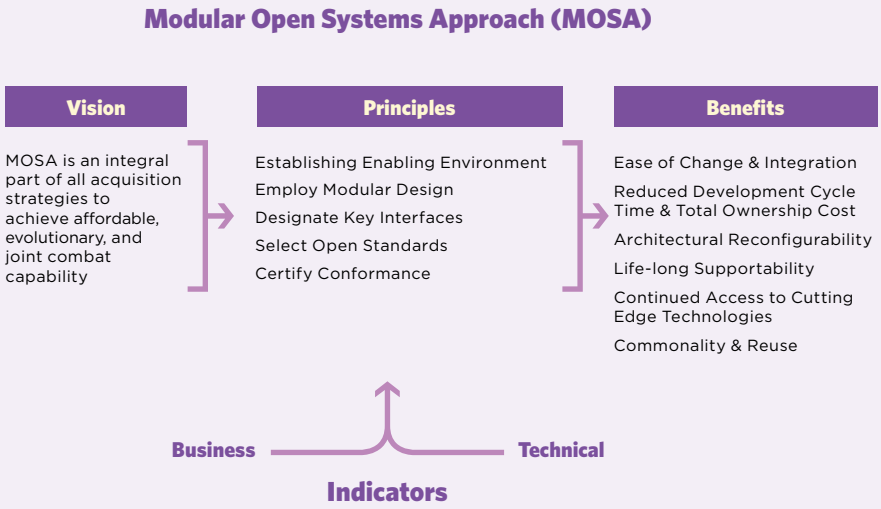


Figure 1 depicts the DoD vision, the fundamental principles, and proven benefits of following MOSA. As shown in Figure 1, MOSA must become an integral part of each acquisition strategy to achieve affordable, evolutionary, and joint combat capability. Effective implementation of MOSA is dependent on adherence to five fundamental MOSA principles (Azani & Flowers, 2005). Additional principles have been added to this list which include biotic open systems that have been around for millions of years (Azani, 2009). Although considerable literature exists on developing an open architecture for a new system (Azani, 2009; Azani & Flowers, 2005; Azani, 2000, 2001a, 2001b; Azani & Khorramshahgol, 2005a, 2005b, 2005c, 2006), no coverage of legacy systems migration into open systems is evident. Also lacking are proven models or methodologies to evaluate the feasibility of a migration decision, identification of appropriate migration candidates, and prioritization and implementation of open architectures for the selected candidate systems.

This article proposes an integrative mode/method for migrating legacy systems into open systems in a family or system of systems context. The proposed model/method is equally applicable to migration decisions involving subsystems in a single system. The model/method integrates the Modular Open Systems Approach (MOSA) with two powerful mathematical models, namely the Analytic Hierarchy Process (AHP) and Goal Programming (GP). By incorporating the MOSA concept into the model, decision makers will also enable their programs to: 1) meet challenges associated with integrating technologies from different vendors; 2) maintain continued access to cutting-edge technologies and products from multiple suppliers; 3) facilitate quick development and cost-effective change of legacy applications; and 4) address change management as system requirements evolve and new technologies become available. Through incorporating the two proven mathematical models, the suggested method enables organizations

to effectively consider multiple criteria and conflicting goals in the decision-making process and integrate tangible as well as intangible factors from various stakeholders to reach a more acceptable and best possible decision.

The following sections present a brief introduction to an open system concept and discuss the *legacy migration* challenges organizations face. The AHP and GP are then explained. Finally, the proposed method is discussed and its application illustrated through an example, followed by a discussion of the advantages and limitations of the proposed methodology.

What is an Open System Concept?

The open system concept evolved from biological and physical sciences and was adopted in the information technology industry in the late 1960s and early 1970s (Azani, 2000). For many years, information systems buyers were limited to only a few major mainframe vendors, of which one vendor was clearly dominant in the marketplace. Competition was severely limited because access to the market was controlled essentially by one, or no more than a few, vendors (Azani 2002). A number of different standards organizations initiated open systems efforts, sometimes in competition with one other. Recently, some order has come to the scene, and some degree of convergence appears reasonable.

Open system definitions vary within disciplines, industries, and organizations. Nevertheless, there are some common themes that most of these definitions contain (Roark & Kiczuk, 1995). Generally speaking, open systems are systems with permeable boundaries or well-defined standardized interfaces that enable exchange of energy (e.g., electrical current via a wall plug); material (e.g., replacement of components/parts with equivalent components from competitive sources); and information (e.g., interoperability with other systems) within the joint operating environment (Azani, 2009). Within this context, open systems are defined as systems that employ modular design, use widely supported and consensus-based standards for their key interfaces, and are subjected to successful validation and verification tests to ensure the openness of their key interfaces (Azani & Flowers, 2005). Open architectures enable easier integration of properly engineered modules across a wide range of systems, effective reconfiguration and reintegration into joint warfighting and system of systems constructs, successful exchange of information and services with other modules on local and remote systems, and more affordable and quicker adaptation to evolving needs and technologies.

What is an Open Architecture?

Architecture means different things to different people. Some definitions are complex and depicted in very complicated, confusing, and long sentences (Jazayeri & Linden, 2000; Booch et al., 1999). Other definitions such as the ones

proposed by Rechtin and Maier (1997) are simpler and more concise definitions of architecture. The best architecture definition is perhaps the definition proposed by recognized standards organizations such as the one by the Institute of Electrical and Electronics Engineers that defines architecture as the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time. However, the architecture of a given system seems to be not only the structure of the system, but also its functions, the environment in which it will reside, and the process by which it will be built and operated (Rechtin, 1997). It also represents the highest-level conception of a system in its environment, includes the structure and behavior of the whole system in that environment, and how it will meet its requirements (Emery et al., 1996).

An open architecture depicts the structure of functional and physical modules, their interrelationships through well-defined open key interfaces, and the principles governing the design, development, reconfiguration, and evolution of such structure over time. Open architectures rely on physical modularity and functional partitioning of both hardware and software to create the flexibility needed for replacing specific subsystems and components without affecting others. The open architecture supports the functional baseline and system specifications and is an effective blueprint for developing and maintaining affordable and adaptable applications and systems. Moreover, some organizations are at a higher level of maturity in their application of open architecture, while others operate at very early levels or stages of open systems maturity (Azani, 2002). By developing open architectures, the system integrators/architects will build flexibility into their systems/applications and will achieve enduring interoperability, integrability, affordability, adaptability, and supportability for their systems.

Migration Issues and Challenges

Organizations face a number of formidable challenges in their decision making process of migrating legacies into open systems:

- How does an organization determine which legacy systems should be kept, modernized, and be migrated into open systems?
- How does the organization tackle the integration of legacy systems into joint warfighting system of systems constructs?
- How does the organization mitigate the risks associated with obsolescence and unavailability of components comprising a legacy system?
- How does the organization avoid the legacy dependence on a single source of supply for the remainder of legacy useful life?
- In case the organization decides to keep the functionality of legacy systems, how does the organization reach consensus

on objectives and criteria needed for analyzing the existing functionality, evaluating their future relevance, and assessing the feasibility of their migration into open systems?

- How should the organization prioritize migration candidates, allocate resources, and develop open architectures for them?
- How does the organization deal with complexity and risks of migration and integration considering the many applications, diverse networks, various standards, and numerous platforms that exist in a typical organization?
- How does the organization deal with multiple conflicting objectives in migrating legacies into open systems?

Other challenges that decision makers face are to establish objective criteria to compare different legacy systems and select the migration candidates. Examples of such criteria are remaining useful life of the legacy system, expected life cycle cost savings as a legacy system is migrated into an open system, and the extent of future risk avoidance. Unfortunately, in most organizations the criteria used for comparison are subjective, and decision makers cannot reach a consensus on the magnitude of risks, costs, or system useful life. They are also less likely to agree on likelihood of occurrence of various types of risks encountered if the legacy system is not migrated.

Seamless integration of legacy systems can be a very complex and tedious project, across numerous applications, diverse networks, various standards, and many platforms in an organization. System integration not only is a challenging task, it is also quite risky. Not surprisingly, 88 percent of integration projects fail (Pollock, 2001). Most if not all of the legacy system integration challenges mentioned above can effectively be addressed by using the proposed methodology and by making every system a part of an integrated network of open architectures. The proposed methodology will rely on an integrated product and process teaming arrangement to establish agreed-upon objectives and criteria needed for comparison of legacy systems. After establishing objectives and criteria, the problem would be to prioritize migration candidates based on these criteria and allocate resources among them. To this end, the proposed methodology applies AHP for prioritization of legacy systems and GP for resource allocation. A powerful feature of GP is its ability to allow for consideration of multiple conflicting goals and objectives when allocating organizational resources.

Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (Saaty 1980) is based on the idea that a complex issue can be effectively examined if it is hierarchically decomposed into its parts. AHP implementation entails a hierarchy whose top level reflects the overall objective. Criteria are listed at intermediate levels, while the lowest level

represents the alternatives. Elements at a certain level are compared to one another with reference to their effect on the higher level. Saaty (1994, 1996) has an inconsistency index to capture any bias when relative comparisons are made. A zero value would indicate perfect consistency, whereas larger values indicate increasing levels of inconsistency. Saaty (1994) states that the Inconsistency Ratio (IR) should be about 10 percent or less to be acceptable. If the IR exceeds the 10 percent level, value judgment may need to be revised. AHP has been applied in a number of areas ranging from engineering, economics, and politics, to marketing, sociology, and management. Vargas and Zahedi (1993) present a comprehensive survey of AHP and its applications.

AHP is a valuable component of the proposed methodology because: a) it considers the legacy system migration problem in its entirety; b) it breaks the problem down into its components and subcomponents; and c) it incorporates multiple (conflicting) objectives, uncertainty, and decision makers' preferences in the decision-making process. In addition, AHP allows for multiple stakeholders to participate in the decision making process. For excellent discussions of AHP applications, see Saaty (1994, 1996), Liberatore (1987), Vargas and Zahedi (1993), Liberatore and Nydick (2003), and Wasil and Golden (1991).

Goal Programming

GP deals with allocating scare resources among alternatives in the best possible way, by mathematically stating the problem so as to minimize a given function subject to a set of constraints. The procedure starts with specifying a target or aspiration value for each objective, thus transforming all objectives into goals. The resultant objective function—termed achievement function—is then the summation of deviations from these goals. Since attaining all goals simultaneously is impossible, the problem is then to minimize the sum of the deviations from the goals; that is, to minimize the achievement function.

GP initially was developed by Charnes and Stedry (1964) and extended and improved by Jaaskelainen (1969) and Ignizio (1976, 1982). Ijiri (1965) also suggested the concept of "preemptive priorities," where a priority is given to an objective or a set of commensurable objectives.

The GP model, as described by Ignizio (1982), follows:

Find $x = x_1,\ldots,x_j,\ldots x_J$ so as to minimize:

$a = g_1(n,p),\ldots g_k(n,p),\ldots g_K(n,p)$

such that:

$f_i(x) + n_i - p_i = b_i$ for all $i = 1,\ldots,m$

and $x, n, p \geq 0$,

where:

"xj" is the jth decision variable,

"a" is denoted as the achievement function; a row vector measure of the attainment of the goals or (rigid) constraints at each priority level,
"$g_K(n,p)$" is a function (normally linear) of the deviation variables associated with the objectives or constraints at priority level k,
"K" is the total number of priority levels in the model,
"b_i" is the right-hand side constant for goal (or rigid constraint) i,
"$f_i(x)$" is the left-hand side of the linear or nonlinear goal or constraint i.

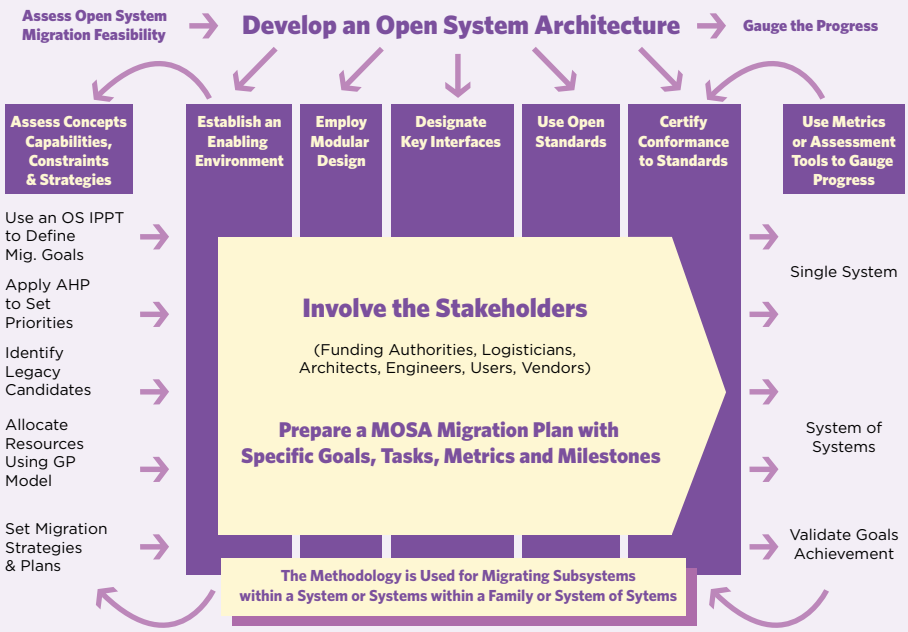
The Proposed Methodology

As mentioned earlier, the proposed methodology employs the MOSA concept, applies an Integrated Product and Process Team (IPPT) approach, and uses AHP and GP models. Such concepts and models are integrated together to evaluate, plan, and monitor the application of the methodology; set priorities among legacy candidates; allocate resources among them; and finally, develop open architectures for the selected migration candidates.

The major constructs of the proposed method are depicted in Figure 2 and its practicability and applicability will be demonstrated by a hypothetical naval organization in subsequent section of this article.

The methodology utilizes three major phases and a number of steps within each phase, as detailed in the following discussion.

FIGURE 2. THE PROPOSED MIGRATION METHODOLOGY



PHASE 1: MAKE A BUSINESS CASE FOR MIGRATION AND ESTABLISH A MIGRATION PLAN

At this phase, the team that oversees the application of the methodology is appointed, legacy system candidates are identified and prioritized, the GP problem is formulated, and organizational resources will be allocated among selected migration candidates.

Step 1.1. Use an IPPT to identify legacy systems in need of migration and assess their functionality; determine which legacy system should be kept, modernized, or eliminated; establish migration objectives and evaluation criteria; and oversee the entire migration process. The IPPT may select diverse and conflicting objectives. However, this will not present any problem as GP allows for multiple, conflicting, and non-commensurable objectives of the organization to be included in problem formulation. The preferred IPPT format will be a Delphi inquiry to remove Groupthink and bias from the process, assure anonymity and continuing feedback, and allow for a more refined and comprehensive analysis of the problem (Linstone & Turoff, 1975).

Step 1.2. Apply AHP to set priorities among the legacy systems identified earlier using the evaluation criteria identified in Step 1.1. In other words, the set of legacy system candidates generated in the previous step is presented to the members of the IPPT to obtain their subjective value judgments for a pair-wise comparison matrix. The eigenvalues of this matrix represent the priorities among the criteria selected as well as the priorities among the various legacy system candidates. The priorities among the selected criteria will then be used as penalty weights in the objective function of the GP model.

Step 1.3. Using the information obtained in the two previous steps, the IPPT will formulate a GP model to allocate resources among the selected migration candidates.

Step 1.4. Establish proper migration plans and strategies (acquisition, logistics, test and evaluation, etc.) to cost effectively transform the selected legacies into open systems. The migration strategies should also specify when, how, and in what order the migration efforts should proceed.

PHASE 2: DEVELOP OPEN ARCHITECTURES FOR MIGRATING SYSTEMS

At this phase, through compliance with the five MOSA principles identified earlier, an open architecture will be developed for each approved legacy system candidate.

Step 2.1. Establish an enabling environment. Effective MOSA implementation is contingent upon adequate skills and training on the open systems concept; suitable acquisition and logistics verification and validation strategies; and

establishment of an appropriate MOSA implementation roadmap with milestones and performance measures.

Step 2.2. Employ modular design tenets to repartition the legacy system into encapsulated, cohesive, and self-contained modules with well-defined internal and external interfaces.

Step 2.3. Group interfaces into key and non-key interfaces using criteria such as the rapid rate of technology turnover, high cost, interoperability requirement, and the failure rate of modules at each end of an interface.

Step 2.4. Use widely supported and consensus-based (open) standards for key system interfaces to develop an open architecture for the system.

Step 2.5. Use proper verification and validation mechanisms to ensure openness of key interfaces and the overall system architecture.

PHASE 3: GAUGE THE PROCESS AND TAKE CORRECTIVE ACTION

During this phase proper contracting language, performance measures, and validation criteria are established to ensure openness of the selected migration systems.

Step 3.1. Use appropriate contracting language (e.g., section L and section M stipulations) to ensure that subsystems, components, and commercial products delivered are open.

Step 3.2. Use appropriate performance measures (metrics) to assess the MOSA implementation progress and system openness. Examples of such metrics are the percentage of key interfaces defined by open standards, and percentage of system modules that can be acquired from multiple competitive sources when the system is migrated.

Step 3.3. Validate that the migration goals and objectives are achieved.

Application of the Proposed Model

To demonstrate its practicability and applicability, the methodology is applied to a hypothetical SoS portfolio of existing naval systems. Let us assume that the IPPT selected by the SoS Program Executive Office has decided to use the proposed model/method and has conducted an inquiry and reached a consensus on the following organizational objectives/criteria to be pursued for the next ten years:

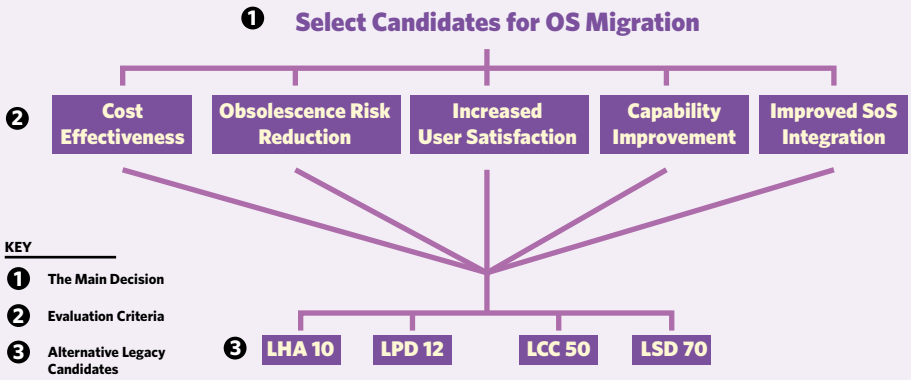
Goal 1. Reduce total ownership cost—measured by the net present worth of total projected cost saving/avoidance resulting from gaining access to multiple sources of supply and migration to an open system architecture.

Goal 2. Reduce obsolescence risks—measured by the number of open standard-compliant products in the migrated system.

Goal 3. Improve availability and reliability—measured by an increase in system reliability and availability resulting from the latest COTS hardware and software products enabled and employed by the migrated system.

Goal 4. Improve system capability—measured by the percentage improvement in the overall system capability when its architecture is migrated into an open systems architecture. Figure 3 shows a recommended approach for measuring risks and the impacts on capability if a legacy system does not become open.

FIGURE 3. THE AHP MODEL FOR THE ILLUSTRATIVE EXAMPLE



Goal 5. Enhanced integration and interoperability—measured by the number of key internal and external interfaces that will be defined by open standards as the system migrates into an open architecture.

Let us assume that the funds allocated among the candidate legacies must be proportional to the level of contribution of each legacy system toward the achievement of the goals listed above. This requirement will bring four new constraints into the GP formulation. Table 1 depicts the target level for each objective/goal as specified by the IPPT.

Let us further assume that goals 1, 2, and 4 must be achieved, at a minimum, by the amount specified, and an exact achievement of goals 3 and 5 is desired.

Let us assume that after careful consideration of the functionality, modernization options, and life expectancy of all the legacy systems in the SoS portfolio of naval systems, four hypothetical legacy systems (i.e., LHA 10, LPD 12,

TABLE 1. THRESHOLDS/TARGET LEVELS FOR EACH GOAL

Objective	Target Level
Improve Cost Effectiveness (at least)	$12,000,000
Reduction in Obsolescence Risk (at least)	100
Improve Overall User Satisfaction	20%
Improve Overall Systems Capability (at least)	60%
Enhance System of Systems (SoS) Integration	80

Use AHP to assign weights to these goals.

Use Goal Programming to minimize deviation from these goals and compute fund allocation percentages.

LCC 50, and LSD 70) were found to be suitable candidates for migration to open systems. Figure 4 depicts the hierarchy structure of the problem.

Let us further assume that the following preferences, based on Table 2, were elicited from the participants of the open systems migration IPPT or Delphi inquiry using the AHP preference criteria:

- Criterion 1 is very strongly preferred to criterion 2
- Criterion 1 is strongly preferred to criterion 3
- Criterion 1 is equally to moderately preferred to criterion 4
- Criterion 1 is extremely preferred to criterion 5
- Criterion 2 is moderately preferred to criterion 5
- Criterion 3 is strongly preferred to criterion 2
- Criterion 3 is moderately to strongly preferred to criterion 5
- Criterion 4 is very strongly preferred to criterion 2
- Criterion 4 is strongly preferred to criterion 3
- Criterion 4 is extremely preferred to criterion 2

TABLE 2. PAIRWISECOMPARISON MATRIX FOR CRITERIA

Criteria	1	2	3	4	5	Criteria Weight
1	1	7	5	2	9	0.448
2		1			3	0.053
3		5	1		4	0.125
4		7	5	1	9	0.343
5					1	0.031

FIGURE 4. A RECOMMENDED APPROACH FOR MEASURING CAPABILITY IMPACTS

Time Horizon & Probability		Risk Intensity if the System does not Become Open		
		Severe Impact	Moderate Impact	Negligible Impact
	Near Term	High	High	High
		Medium	Medium	Medium
		Low	Low	Low
	Mid Term	High	High	High
		Medium	Medium	Medium
		Low	Low	Low
	Long Term	High	High	High
		Medium	Medium	Medium
		Low	Low	Low

Sever Impact: Enormous shift in adversaries' capability or technology causing major degradation of system capability (assigned value: twice as severe as moderate risk or .60)
Moderate Impact: Some shift in adversaries capability or technology causing moderate capability degradation in near future (assigned value: three times as severe as negligible risk or .30)
Negligible Impact: Negligible shift in adversaries' capability or technology causing negligible capability degradation (assigned value = .10)

Using the above preferences, the matrix in Table 2 was constructed for the pair-wise comparison of criteria and their relative weights. A number of AHP decision support software (e.g., Expert Choice, simple spreadsheet algorithm, etc.) are available to bypass the tedious calculations and quickly find the weights/priorities.

Similarly, pair-wise comparison matrices for four candidate legacy systems (i.e., LHA 10, LPD 12, LCC 50, and LSD 70), with respect to each criterion, were established. An example of these matrices and the AHP evaluation criteria is shown in Figure 5.

Table 3 shows the final assigned weight for the four legacy candidates.

TABLE 3. THE OVERALL SYSTEM WEIGHTS

Legacy Systems	Weight
LHA 10 (System A)	0.140
LPD 12 (System B)	0.114
LCC 50 (System C)	0.262
LSD 70 (System D)	0.484

FIGURE 5. SETTING LEGACY SYSTEMS PRIORITIES USING AHP EVALUATION CRITERIA

Improved Integration	LHA 10	LPD 12	LCC 50	LSD 70
LHA 10	1	2	3	5
LPD 12	0.5	1	5	7
LCC 50	0.33333333	0.2	1	3
LSD 70	0.2	0.142857143	0.33333333	1

KEY

1	Equally preferred
2	Equally to moderately preferred
3	Moderately preferred
4	Moderately to strongly preferred
5	Strongly preferred
6	Strongly to very strongly preferred
7	Very strongly preferred
8	Very strongly to extremely preferred
9	Extremely preferred

Legacy Systems	Weight
LHA 10 (System A)	0.140
LPD 12 (System B)	0.114
LCC 50 (System C)	0.262
LSD 70 (System D)	0.484

As mentioned earlier, it is desired that the organizational resources be allocated among different legacy systems in direct proportion to the weights assigned to them by AHP. Thus, the following relationships should hold true:

$$\frac{X_A}{0.140} = \frac{X_B}{0.114} = \frac{X_C}{0.262} = \frac{X_D}{0.484}$$

The following equations are derived from the above set of ratios:

$$0.114\ X_A - 0.140\ X_B = 0$$
$$0.262\ X_A - 0.140\ X_C = 0$$
$$0.484\ X_A - 0.140\ X_D = 0$$
$$0.262\ X_B - 0.114\ X_C = 0$$
$$0.484\ X_B - 0.114\ X_D = 0$$
$$0.484\ X_C - 0.262\ X_D = 0$$

These equations will be used as constraints in GP model formulation. Using the criteria weights shown in Table 2, we will now formulate a GP model to allocate resources among the migration candidates. As discussed earlier, the priorities among the criteria will be used as penalty weights in the objective function of the GP model. Table 4 shows the parameters needed for formulation of the GP model.

TABLE 4. GP CONSTRAINTS AND PARAMETERS

	Criteria					
Legacy System	*1*	*2*	*3*	*4*	*5*	**Legacy System Weight**
LHA 10	$3,000,000	20	15%	20%	15	0.140
LPD 12	$1,750,000	40	10%	25%	30	0.114
LCC 50	$6,000,000	35	5%	10%	20	0.262
LSD 70	$8,000,000	25	5%	15%	35	0.484
Target Level	$12,000,000	100	20%	60%	80	1.00

Criteria: 1. Improve Cost Effectiveness, 2. Reduction in Obsolescence Risk, 3. Improve System User Satisfaction, 4. Improve System Capability, 5. Enhance System of Systems Integration

The GP model for this problem is as follows:

Minimize: $0.448\ N_1 + 0.053\ N_2 + 0.125\ N_3 + 0.125\ P_3 + 0.343\ N_4 + 0.031\ N_5 + 0.031\ P_5$

Subject to:

$3\ X_A + 1.75\ X_B + 6\ X_C + 8\ X_D + N_1 - P_1 = 12$

$20\ X_A + 40\ X_B + 35\ X_C + 25\ X_D + N_2 - P_2 = 100$

$15\ X_A + 10\ X_B + 5\ X_C + 5\ X_D + N_3 - P_3 = 20$

$20\ X_A + 25\ X_B + 10\ X_C + 15\ X_D + N_4 - P_4 = 60$

$15\ X_A + 30\ X_B + 20\ X_C + 35\ X_D + N_5 - P_5 = 80$

$0.114\ X_A - 0.140\ X_B = 0$

$0.262\ X_A - 0.140\ X_C = 0$

$0.484\ X_A - 0.140\ X_D = 0$

$0.262\ X_B - 0.114\ X_C = 0$

$0.484\ X_B - 0.114\ X_D = 0$

$0.484\ X_C - 0.262\ X_D = 0$

End.

X_A, X_B, X_C, and X_D represent the contribution level of each legacy system to the five goals specified earlier. Solving the above GP problem, the final solution is as follows:

$X_A = 0.540889$; $X_B = 0.440438$; $X_C = 1.012234$; $X_D = 1.869929$

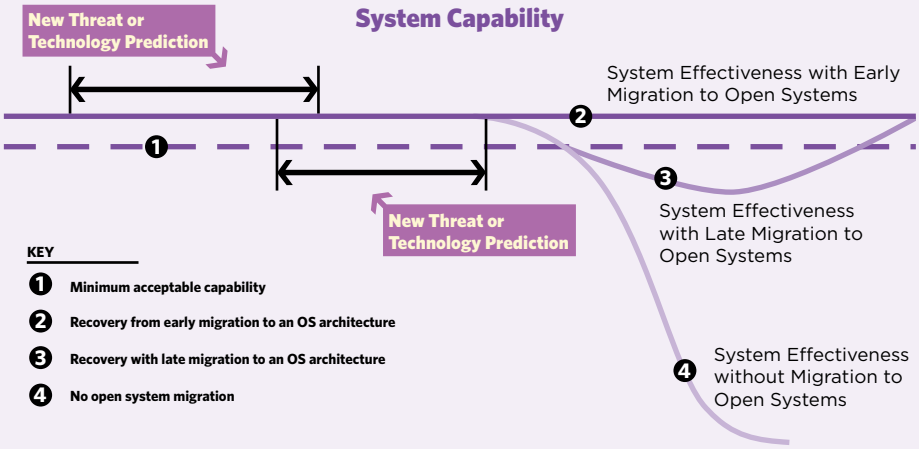
This solution specifies that the organizational resources should be allocated among the four legacy systems based on the following percentages:

LHA 10: [0.540889/(0.540889 + 0.440438 + 1.012234 + 1.869929)]* 100 = 14 %
LPD 12: [0.440438/(0.540889 + 0.440438 + 1.012234 + 1.869929)]* 100 = 12 %
LCC 50: [1.012234/(0.540889 + 0.440438 + 1.012234 + 1.869929)]* 100 = 26 %
LSD 70: [1.869929/(0.540889 + 0.440438 + 1.012234 + 1.869929)]* 100 = 48 %

Therefore, legacy systems LHA 10, LPD 12, LCC 50, and LSD 70 should receive 14 percent, 12 percent, 26 percent, and 48 percent of the total available resources (funds), respectively. It should be noted that legacy systems LCC 50 and LSD 70 receive about 75 percent of the funds. This high resource allocation ratio is commensurate with the relatively larger contribution of these legacy systems towards achievement of the goals and objectives specified by the IPPT decision makers.

Besides proper allocation of organizational resources, the proposed methodology will also facilitate and expedite the migration decision-making process. This latter feature of the proposed model (i.e., enabling early migration to open systems) should not be taken lightly. As depicted in Figure 3, failing to migrate in a timely manner can result in degraded system capability and effectiveness. As shown in Figure 6, system capability and effectiveness is maintained by early detection/prediction of capability degradation and prompt migration to an open system architecture.

FIGURE 6. EARLY VS. LATE MIGRATION STRATEGY



Advantages and Limitations of the Proposed Method

Six distinct advantages may be derived from the proposed methodology outlined in this article:

- The methodology works as a decision support system that integrates well-established and widely used concepts (i.e., MOSA, IPPT, Delphi) and mathematical models (i.e., AHP, GP).
- The methodology is a multi-criteria resource allocation tool, which incorporates multiple conflicting goals and provides a systematic approach to establish priority among various criteria and competing alternatives.
- The application of the methodology minimizes groupthink, facilitates brainstorming, and enables reaching consensus.
- The methodology enables systems engineers and architects to develop an open architecture for the selected migration candidates.
- The methodology ensures lower total cost of ownership; continued system effectiveness and capability; and extended useful life for subsystems, systems, family of systems, and system of systems.
- By applying the proposed methodology, the program managers can more easily integrate systems in a family or system of systems and continually leverage the investments made in commercial products, practices, and technologies.

Some limitations of the proposed method are the tedious and perhaps time-consuming IPPT process for establishing objectives, and determining the entries for numerous pair-wise comparison matrices. The use of complex mathematical formulas may be another drawback of the model although powerful software exists for AHP and GP computations.

Conclusions

This article proposed an integrative method for assessing the appropriateness of migrating closed legacy systems into affordable and adaptable open systems, and developing open architectures for the selected candidates. The method employed the MOSA concept, applied an Integrated Product and Process Team approach, and used Analytic Hierarchy Process and Goal Programming models as an integrated multi-criteria decision-making model. The methodology capitalized on AHP and GP benefits such as objectivity, consideration of tangible and intangible factors in decision making, and simultaneous incorporation of multiple conflicting objectives in the decision-making process. The methodology also took advantage of open systems benefits. The benefits of open systems—such as adaptive modular architecture and increased portability and interoperability—can significantly enhance an organization's core competencies by reducing the total cost of system ownership, increasing long-term viability, and shortening the length of development cycle time for systems and applications.

Author Biography

Dr. Cyrus Azani is a senior systems engineer at Northrop Grumman and has over 25 years of professional and consulting experience in program/project management, systems engineering, development of open systems architecture, and application of management science models and tools. He is a certified systems engineering and acquisition professional with a Doctor of Science degree in Systems Engineering and Engineering Management. Azani is also the author or co-author of over 50 technical publications.

(E-mail address: cyrus.azani.ctr@osd.mil)

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TECHNOLOGY CORNER:

GAMES FOR GOOD—HOW DAU IS USING GAMES TO ENHANCE LEARNING

Alicia Sanchez

The use of games has become a popular initiative in many learning organizations. The Defense Acquisition University, by targeting enhanced outcomes for learners and using innovative, multiple approaches to develop games and simulations that are engineered to yield performance-oriented outcomes, has created a unique opportunity to reach an evolving workforce on multiple levels. Through the use of story and interaction, students gain a better understanding of the dynamic application of course content, while fostering motivation to learn and increasing perceived relevance of the instruction. This article covers the use of games and simulations in three different initiatives: Games in Curriculum, Games in Continuous Learning Modules, and Mini-Games—each of which was created with the end result of learning in mind.

image designed by Miracle Riese »

Games and Simulations at DAU

Background

As the Defense Acquisition University (DAU) prepares for a younger workforce and the increased performance capabilities that will be expected of that workforce, it has simultaneously transitioned its curricula from a more traditional, educationally focused organization to a true training organization. Within DAU, the necessity for preparing students to perform at higher levels has generated an increased emphasis on providing students not just with the information they need to do their jobs, but also the skills necessary to accomplish the unique challenges they will face upon arrival in their workplaces.

This combination of unique needs has caused DAU to innovate and transform a more traditional educational program into one that accepts the increased use of online learning and reductions in classroom "seat time," presenting an opportunity to rebuild the university's classroom lecture environment into one that more closely aligns with a hands-on apprenticeship. This rebuilding is made possible through the caliber of education that DAU provides, particularly in its incorporation of a games and simulations-based initiative, which allows students to experience workplace events that they will face during their classroom and online learning.

While simulations have traditionally been used to provide people with experiences that they might otherwise not have because they are either too expensive, too dangerous, or happen too infrequently, simulations are more frequently being used to address performance-oriented learning objectives in educational and training environments. Most simulations, however, are linear and are only used once. To increase the benefits of using simulations, DAU incorporated gaming characteristics into its curricula because of their proven capacity to increase a student's motivation to interact with the course content in meaningful and targeted ways. This is accomplished through the inclusion of high-level storylines to serve as a unifying scenario for courses, and game themes in order to support the use of increased interactivity. Specifically, using storylines makes it possible to present content that is more relevant to learners. And relevance is a key component to increasing the "perceived value" of the learning experience to the learner. When motivated learners are presented with information in the appropriate context, gaming also facilitates the ability of learners to integrate that information into the mental models where individuals retain and recall their workplace experiences. Therefore, providing the context of the information being presented can increase a student's ability to understand why and when that information can and should be used. This is also theorized to lead to increased ability for a student to transfer that learning experience into their everyday workplace experiences.

In short, the use of game characteristics can enhance the learners' ability to make meaningful connections, retain and transfer knowledge, and motivate them to interact with course content by providing experiences when combined

with simulations. When combined, games and simulations have the ability to provide the learner with experiential learning opportunities that focus on:

- Appropriate Context—The ability to allow learners to use the content in scenarios or situations that are representative of how the content would be used in the real world.
- Cognitive Fidelity—The alignment of the content with processes that are representative of how the information would be used.
- Varied Situations and Replay Opportunities—The ability to provide multiple practice opportunities for content use based on scenarios and situations that are different in key ways in order to expose the students to a variety of experiences with the content; and the ability for a learner to use these tools multiple times in order to try new strategies for how the content could be used.
- Self-Diagnosis—The ability for learners to gain an understanding of their strengths and weaknesses in order to provide them with the information they need to self-monitor their learning process.
- Scaffolding—The ability for information to become increasingly complex as a learner evolves, with previous information being built upon in order to provide a gradual increase in their understanding.

Through these game characteristics, it is possible to provide students with the necessary motivation and relevance (Figure 1) to internalize course content

FIGURE 1. RELATIONSHIPS BETWEEN GAME CHARACTERISTICS AND USER MOTIVATION

and transfer the knowledge gained—complemented by their own personal abilities—to performance-oriented outcomes.

Following much time spent considering where and when games could make a difference, implementation of three separate types of games emerged to address the specific needs of DAU's diverse student population and curricula. These three categories vary in level of specificity of games and are detailed here.

GAMES IN CURRICULUM

The first and most specific category, Games in Curriculum, focuses on games that are aligned highly enough with a course's learning objectives and context to warrant a game being placed in a course. Since acquisition is a very specific process, often these types of games are naturally going to be custom developments. In these types of games, it is important to consider the aspects of the algorithm that predict the meaningful use of a game in order to establish the highest probability of enhancing performance. One example of this type of game lies in the use of a series of games within the Business, Cost Estimating, and Financial Management curriculum. Specifically, a low-level course that serves as a required course for all students in the career field was selected to include a series of related games. While the course selected represented a high-performing course, a content analysis of the course indicated that this course transmitted primarily conceptual knowledge, often including a heavy emphasis on vocabulary memorization while providing case information of little use or context. It was hypothesized that by including games at the end of each of the online courses—eight modules that provided situations in which the information being memorized could be used—students would find more relevance in the information being presented, and therefore would be motivated to retain the information.

The game, named Rat Race (Figure 2), centers around a story of a rat who, after having lived in the Pentagon for many years, has mastered the art of business financial management by listening, befriending, and assisting some of the world's greatest minds in the acquisition process. Under this frame, players are able to practice the lessons learned within the context of their real-world application, but using a fantastical character that is both endearing and engaging.

GAMES IN CONTINUOUS LEARNING MODULES

Continuous Learning Modules (CLM) at DAU are very specific 2- to 4-hour online learning modules that supplement the core curriculum. They often target specific career-centered information related to process-oriented performance characteristics. In the case of one CLM in particular—Procurement Fraud Indicators (PFI)—the content of the module deals with the ability to identify fraud when it takes place in the workplace. Like many judgment-sensitive areas, the nature of this content is shaded in gray area, innuendo, and non-yielding protocol. The continuum gap between novices and experts in these sorts of content areas is

FIGURE 2. REPRESENTATION OF THE BUSINESS, COST, AND FINANCE GAME

often filled with personal experiences and first-hand accounts. In the absence of those, the use of an experiential game can serve to provide students with the varied situations and opportunities to practice in a safe environment.

The PFI capstone game is, at heart, an adventure game, not unlike traditional point-and-click adventure games designed for the personal computer. The game is divided into several different scenarios, each focusing on a specific character that is suspected of committing fraud. Each scenario is divided into two phases.

Phase I. The "Hidden Object Phase"—an exploration mode where the player visits two scenes to collect clues and piece together information about the fraud being investigated. The scenes differ between each scenario, and range from the mundane (a home office) to the exotic (a Navy vessel).

Phase 2. The "Interview Phase"—the point in the game when the player moves to the interrogation room, where the suspect is questioned about the situation to gather more information. In the Interview Phase, three theories are presented, each using the same clues to draw different conclusions. The player can investigate any or all of the theories, drawing his or her own conclusions from the information presented.

At the end of each line of questioning, the user can attempt to identify the fraud that occurred and the indicators that suggest it (encapsulated by the

three theories). Finding the correct fraud with the correct reasoning results in the player "winning" the scenario; otherwise, the player can try other theories until successful.

FIGURE 3. REPRESENTATION OF THE PROCUREMENT FRAUD INDICATORS GAME

MINI-GAMES

Mini-games—simple downloadable games that are commonly found in conventional Web-based training courses—should no longer be considered as nothing more than a distraction, breaking up the content from the inevitable test that will be presented on the next page. By applying new design patterns, mini-games have come into their own as a legitimate form of training and education. DAU is incorporating mini-games into a Web repository that allows students to brush up on their core topical knowledge of acquisition-related competencies.

Mini-games are usually small games that are easy to learn, but hard to master. Anyone can play "Tetris," but it is difficult to play Tetris well. While conventional games might take days or weeks to play, mini-games are typically played for less than an hour. Educational mini-games follow the same philosophy and contain a single learning objective. Furthermore, the design of mini-games has matured from simple matching games and quizzes, to real and meaningful interaction with training concepts as will be demonstrated. These mini-games are used as homework assignments, remediation, pre-course materials, or just as stand-alone, self-motivated training by the AT&L workforce.

One such game currently in production was designed to introduce students to the seven tools of Continuous Process Improvement (CPI). This game focuses

on a student's ability to understand when and why the tools are appropriate for use, using a fantasy-based alien production line (Figure 3). The story that surrounds this game introduces an alien army heading towards earth. The student does have a weapon that can defeat them, but only a limited amount of time to finish production of enough weapons to defeat the aliens. At the current production rate, there will not be enough weapons to save earth. Using proper CPI methods, players have to improve the process currently in place to increase production and save mankind.

Conclusions

Through insertion of the three types of games and simulations discussed in this article into its course content, DAU will have an opportunity to measure the success of games and simulations and their utility in learning. The insertion of Games in Curriculum, Games in Continuous Learning Modules, and Mini-Games into DAU course content, as well as several other projects currently in development, will pave the way for the university's ultimate transition to a more hands-on, apprenticeship-type learning environment, increased motivation, and increased relevance for students through interactivity and experiential learning tools. Together, these will help engender a culture of performance-oriented learning, culminating in an across-the-board higher level of on-the-job performance excellence.

Author Biography

Dr. Alicia Sanchez specializes in the implementation of games and simulations into a variety of learning environments. Leveraging decades of research in Education and Simulations, Sanchez' focus lies in using games within curricula and emerging technologies, continuously redefining the potential of games-based learning options. Since completing her degree in Modeling and Simulation, she has served as a research scientist at Old Dominion University prior to being named DAU's Games Czar.

(E-mail address: alicia.sanchez@dau.mil)

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- First prize is $1,000. Second prize is $500.
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- The theme for 2010 is: "Achieving Excellence in a Changing Acquisition Environment."
- Research papers are due November 16, 2009.
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Authors should become familiar with the construction of previous *Defense ARJs* and adhere to the use of endnotes versus footnotes, formatting of bibliographies, and the use of designated style guides. *It is also the responsibility of the corresponding author to furnish government agency/employer clearance with each submission.*

SUBMISSIONS

We welcome submissions from anyone involved in the defense acquisition process. Defense acquisition is defined as the conceptualization, initiation, design, development, testing, contracting, production, deployment, logistic support, modification, and disposal of weapons and other systems, supplies, or services needed by the Department of Defense (DoD), or intended for use to support military missions.

RESEARCH ARTICLES

Manuscripts should reflect research or empirically supported experience in one or more of the aforementioned areas of acquisition. Research, lessons learned, or tutorial articles should not exceed 4,500 words. Opinion articles should be limited to 1,500 words.

Research articles are characterized by a systematic inquiry into a subject to discover/revise facts or theories.

MANUSCRIPT SECTIONS

A brief abstract (120-word limit) provides a comprehensive summary of the article and must accompany your submission. Abstracts give readers the opportunity to quickly review an article's content and also allow information services to index and retrieve articles.

The introduction, which should not be labeled, opens the body of the paper and states the problem being studied and the rationale for the research undertaken.

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The discussion section should emphasize the major findings of the study and its significance. Information presented in the aforementioned sections should not be repeated.

RESEARCH CONSIDERATIONS

Contributors should also consider the following questions in reviewing their research-based articles prior to submission:

- Is the research question significant?
- Are research instruments reliable and valid?
- Are outcomes measured in a way clearly related to the variables under study?
- Does the research design fully and unambiguously test the hypothesis?
- Are needed controls built into the study?

Contributors of research-based submissions are also reminded they should share any materials and methodologies necessary to verify their conclusions.

CRITERIA FOR TUTORIALS

Tutorials should provide special instruction or knowledge relevant to an area of defense acquisition to be of benefit to the Defense Acquisition Workforce.

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Opinion articles should reflect judgments based on the special knowledge of the expert and should be based on observable phenomena and presented in a factual manner; that is, submissions should imply detachment. The observation and judgment should not reflect the author's personal feelings or thoughts. Nevertheless, an opinion piece should clearly express a fresh point of view, rather than negatively criticize the view of another previous author.

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DEFENSE ARJ PRINT SCHEDULE 2010

The *Defense ARJ* is published in quarterly theme editions. Please consult the DAU home page for current themes being solicited. See print schedule below.

Due Date	Publication Date
July 1, 2009	January 2010
November 16, 2009	April 2010
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Contributors may direct their questions to the Managing Editor, *Defense ARJ*, at the address shown above, or by calling 703-805-3801 (fax: 703-805-2917), or via the Internet at norene.fagan-blanch@dau.mil.

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